Loads & Aeroelasticity Assessment of Forward Swept and Strut Braced Wings

4th SCAD - Symposium on Collaboration in Aircraft Design

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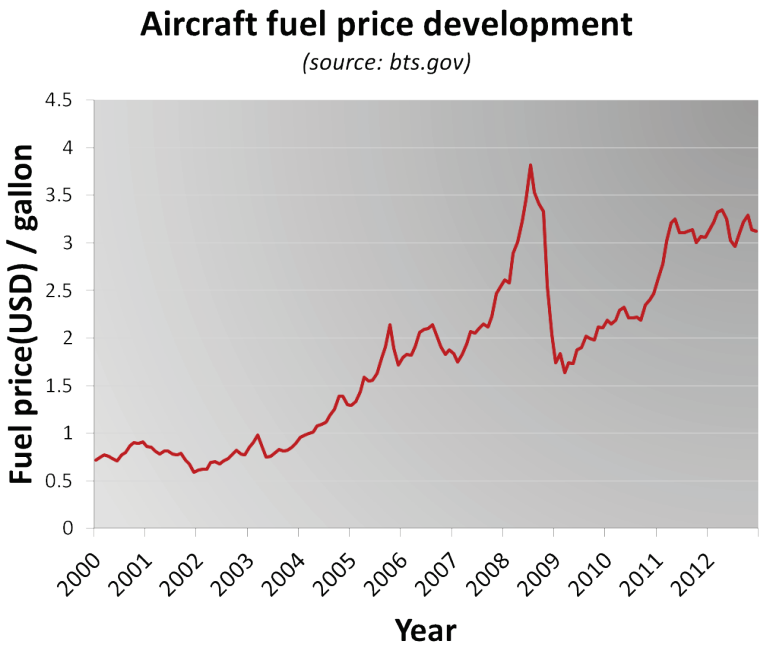
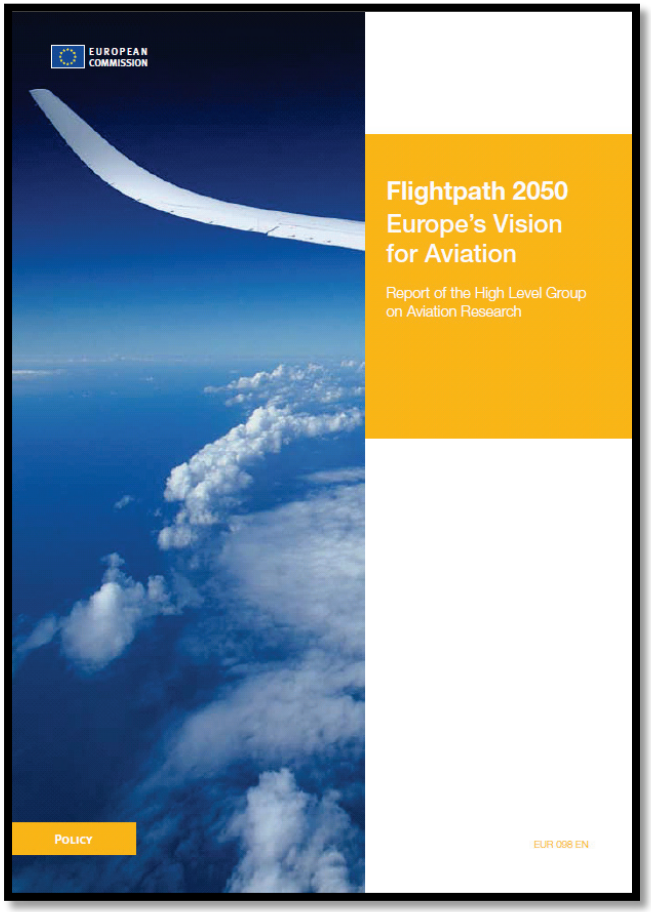
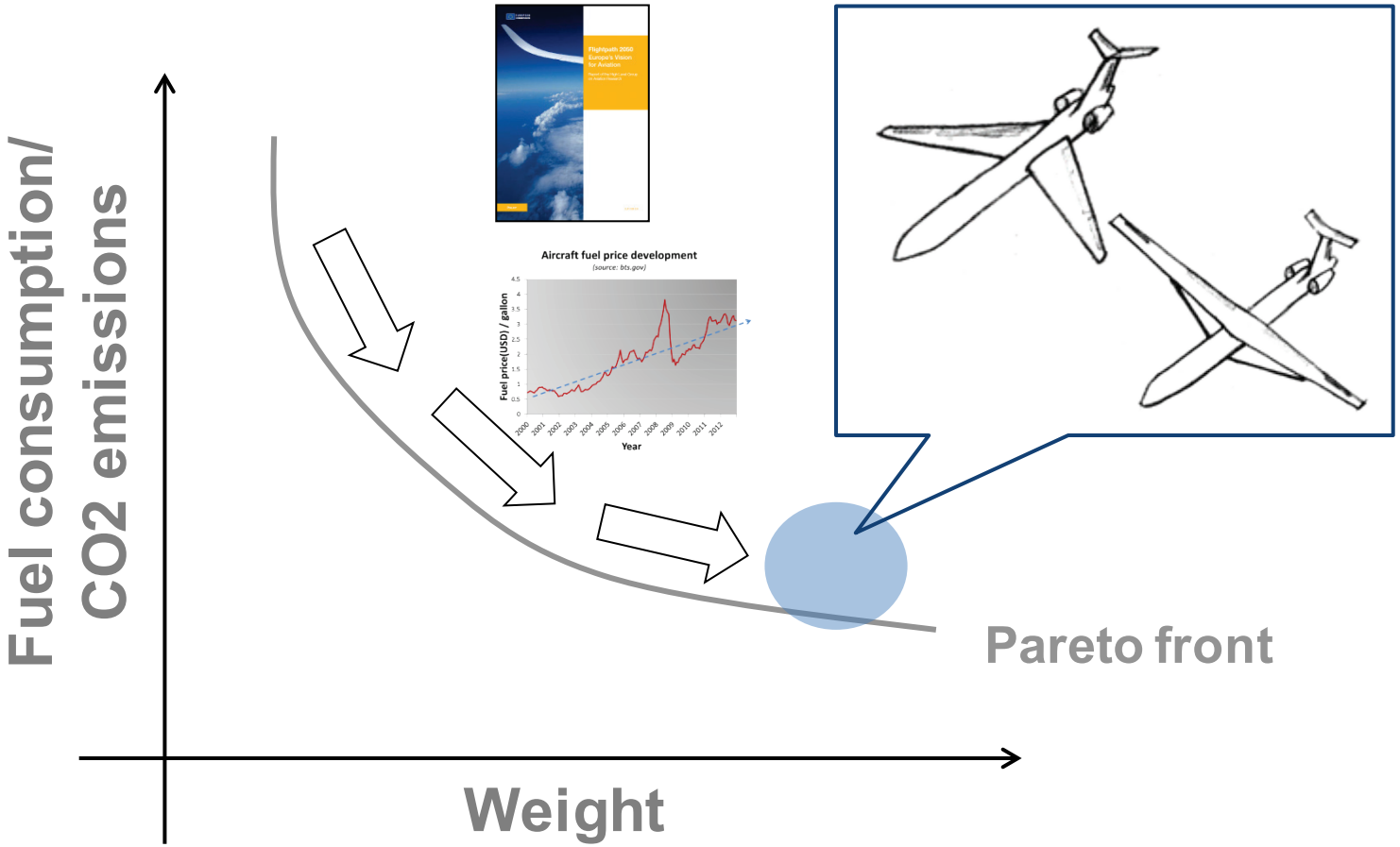
DLR

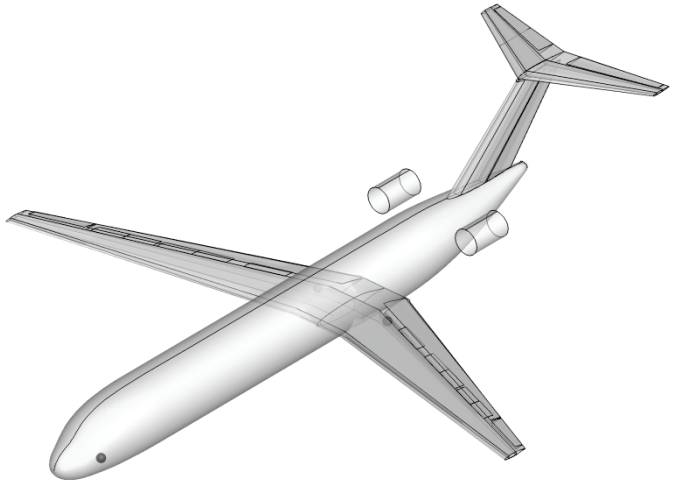
-75% CO2 (2050)





(Source: European Comission, europa.eu)

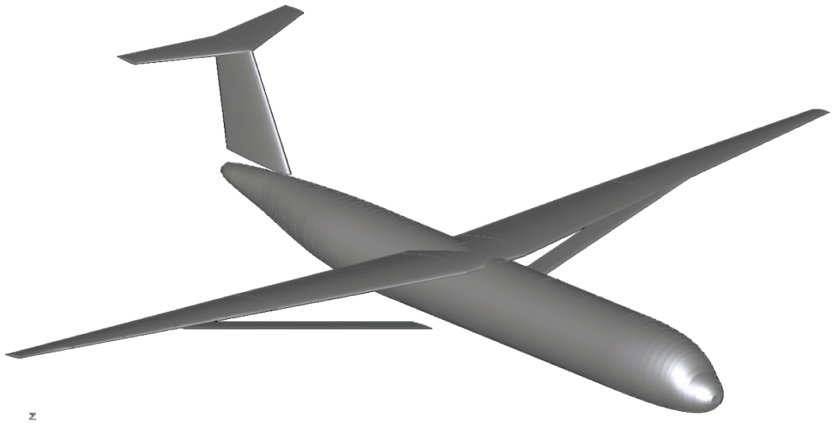

Fuel consumption/
CO2 emissions
Weight
Pareto front
Flightpath 2050
Europe's Vision
for Aviation
Aircraft fuel price development
(source: bts.gov)
Fuel price(USD) / gallon
Year



Forward Swept Wing (FSW)

- ✓ natural laminar flow
- ✓ less twist to achieve lift distribution
- ✓ potential to 10% fuel reduction

- ? higher bending loads
- ? divergence
- ? gust response



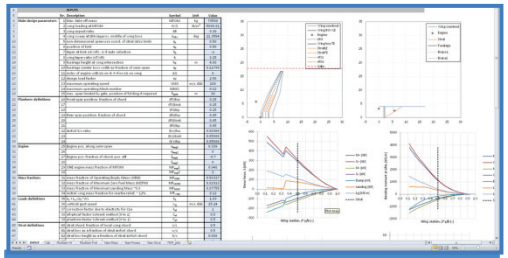
Strut Braced Wing (SBW)

- ✓ higher span / AR -> lower drag
- ✓ lower sweep / (t/c) -> laminar flow
- ✓ less fuel if wing is light enough

- ? changes in loads due to strut
- ? strut weight
- ? flexible wing, aeroelastic effects

Design Studies

... about the methods

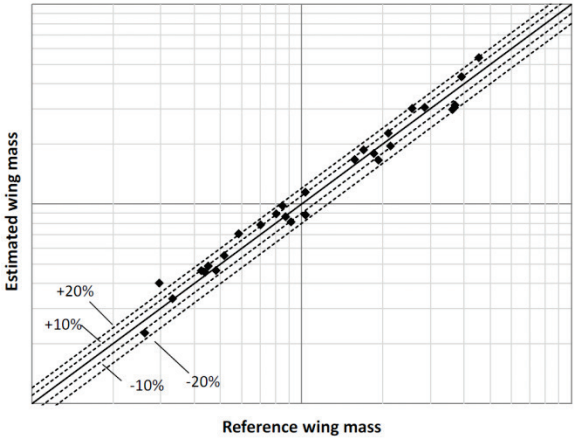


Analytical Loads & Sizing

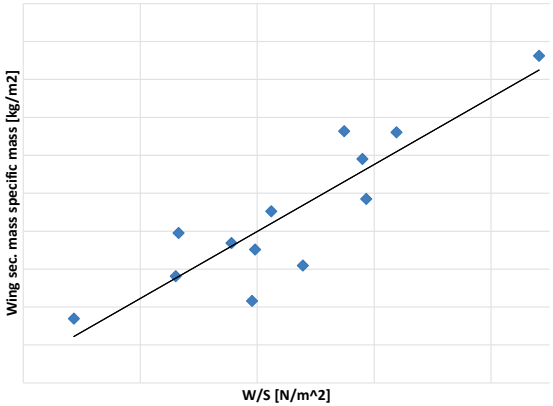
Load cases

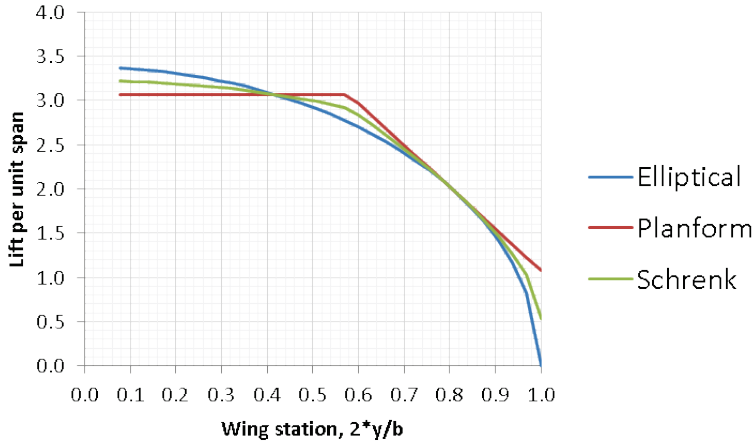
1. M+ (MTOM)
2. G+ (MZFM)
3. M- (MTOM)
4. G- (MZFM)
5. Bump (MTOM)
6. Landing (MTOM)
7. 1g (MTOM+MZFM)/2

Validation



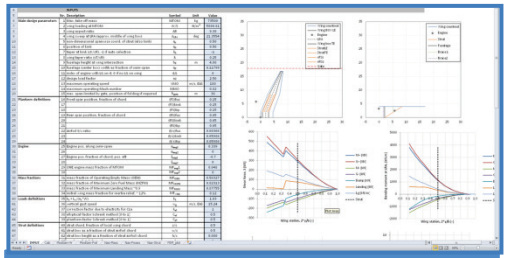
Empirical sec. masses



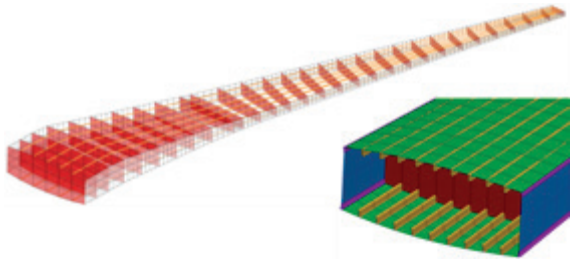


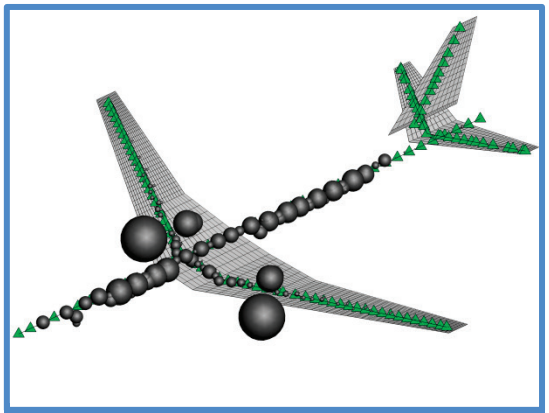
Lift distribution

... about the methods

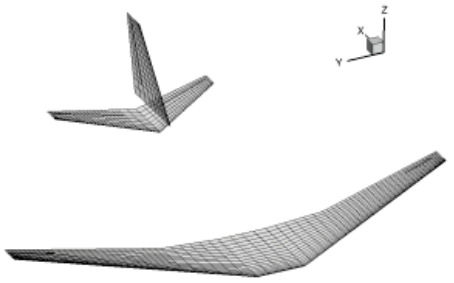


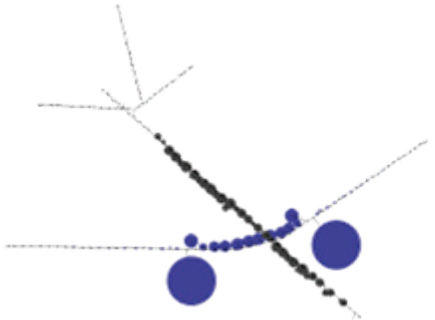
Analytical Loads & Sizing



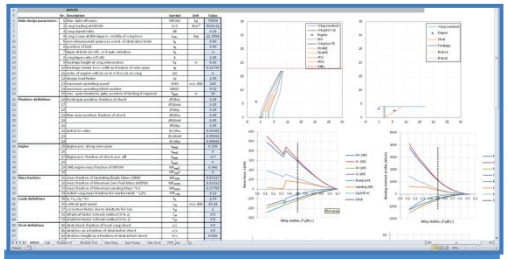


Model Generation

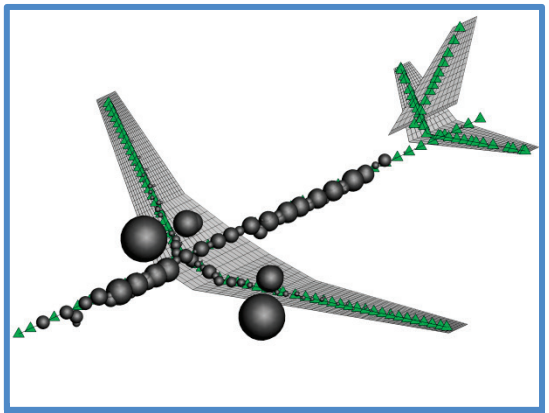




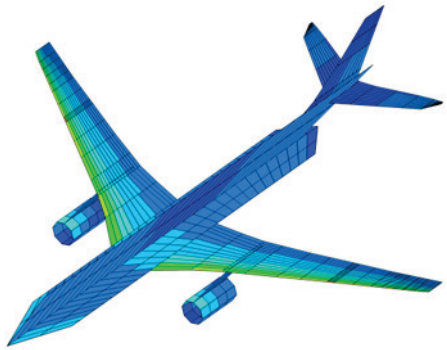
... about the methods



Analytical Loads & Sizing



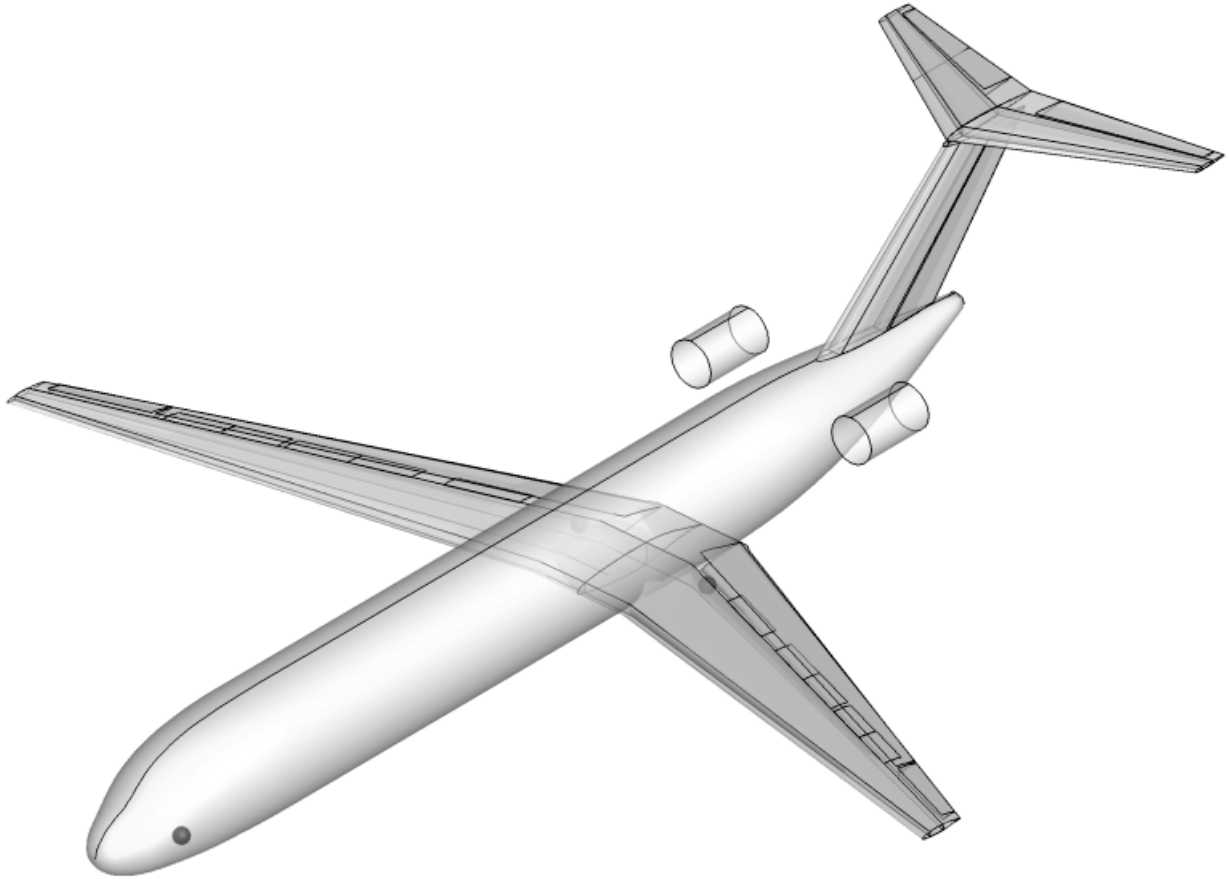
Model Generation

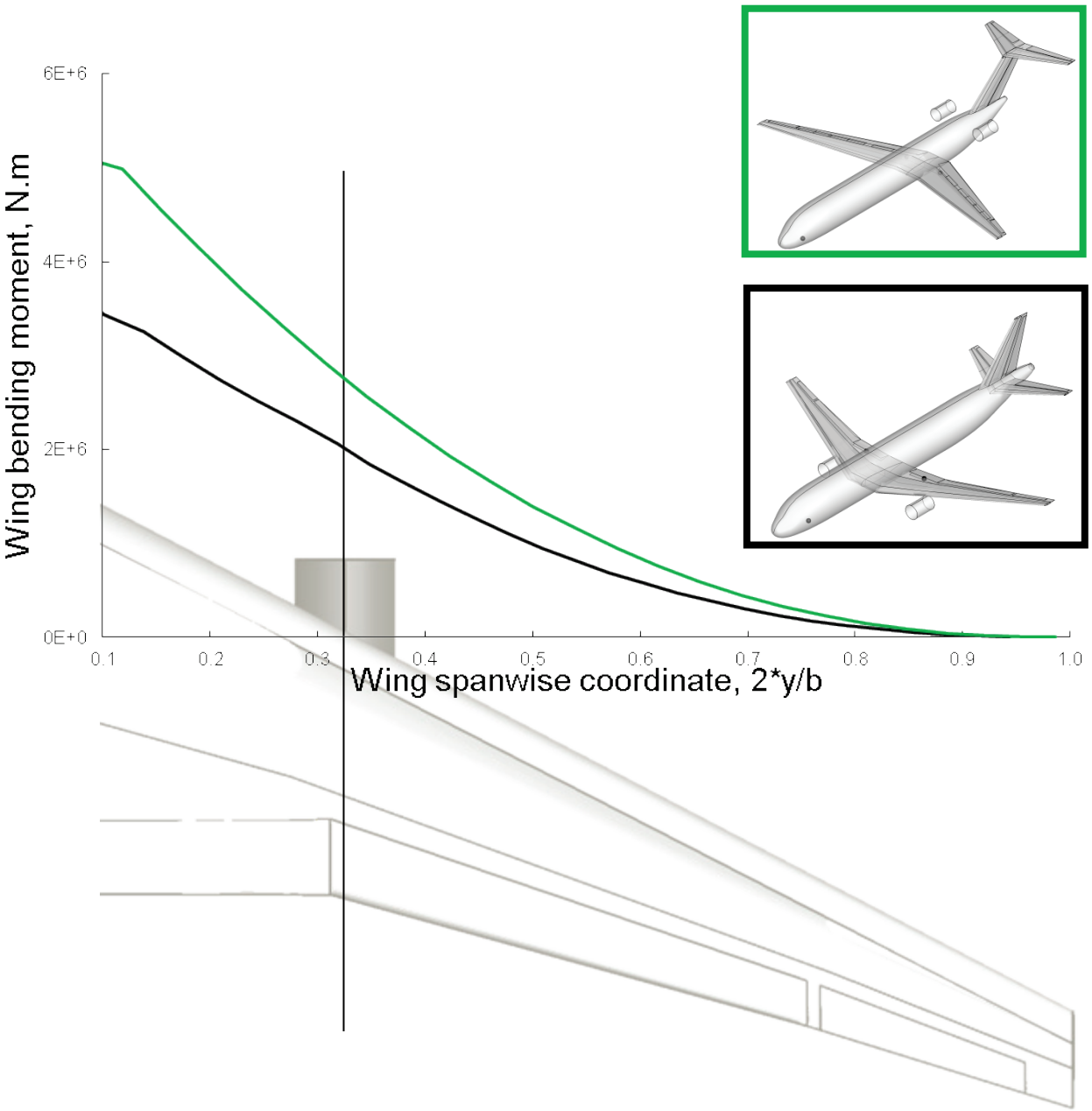


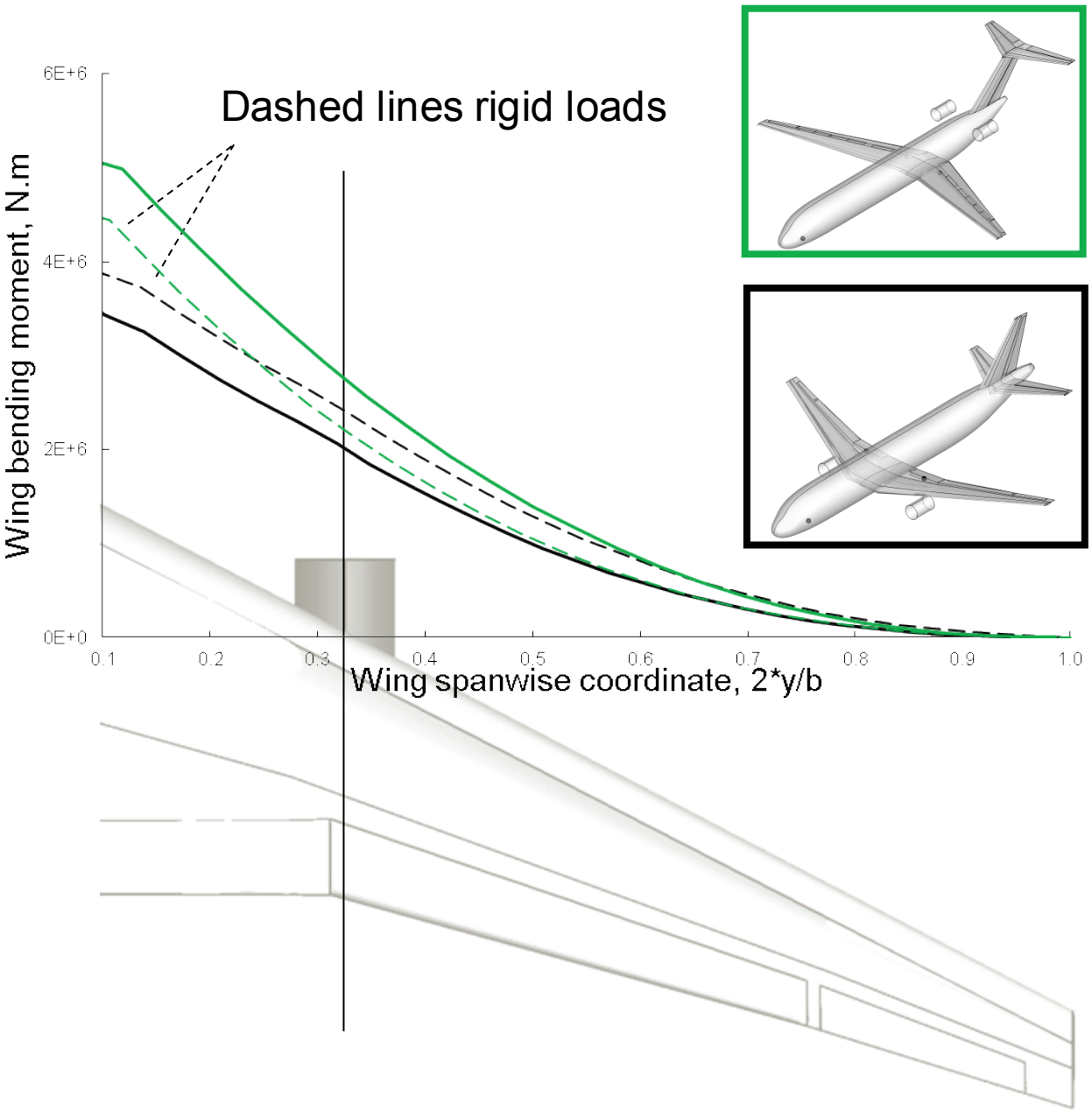
Aeroelastic analyses (NASTRAN)

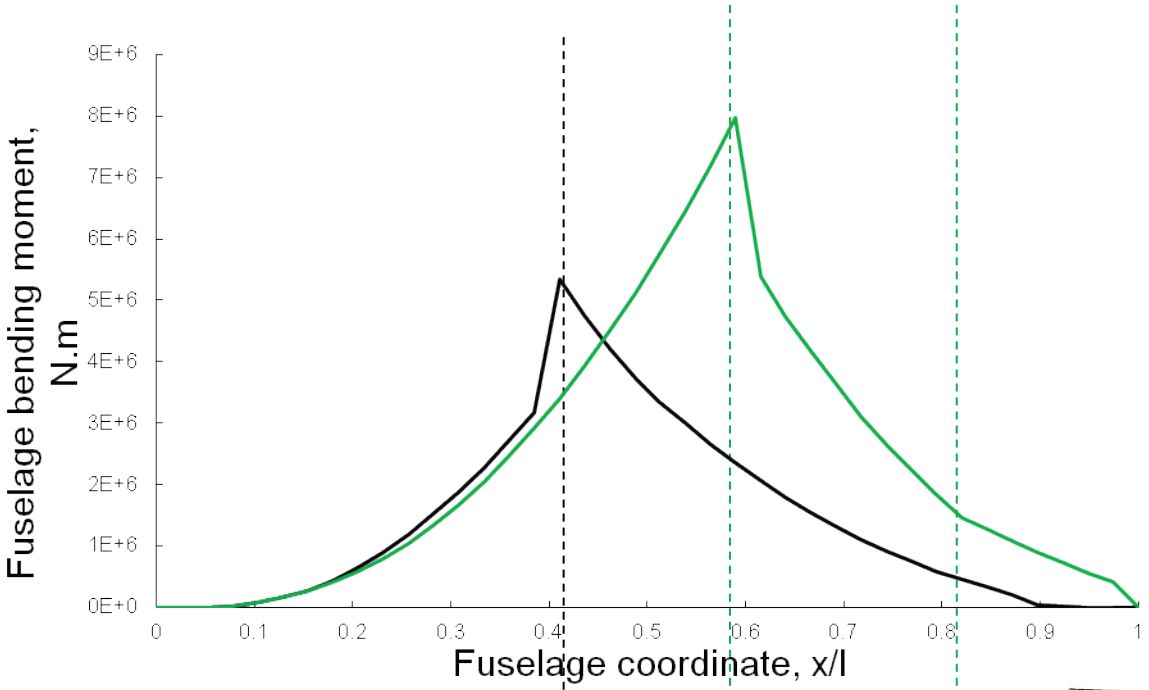
back to the design studies ...

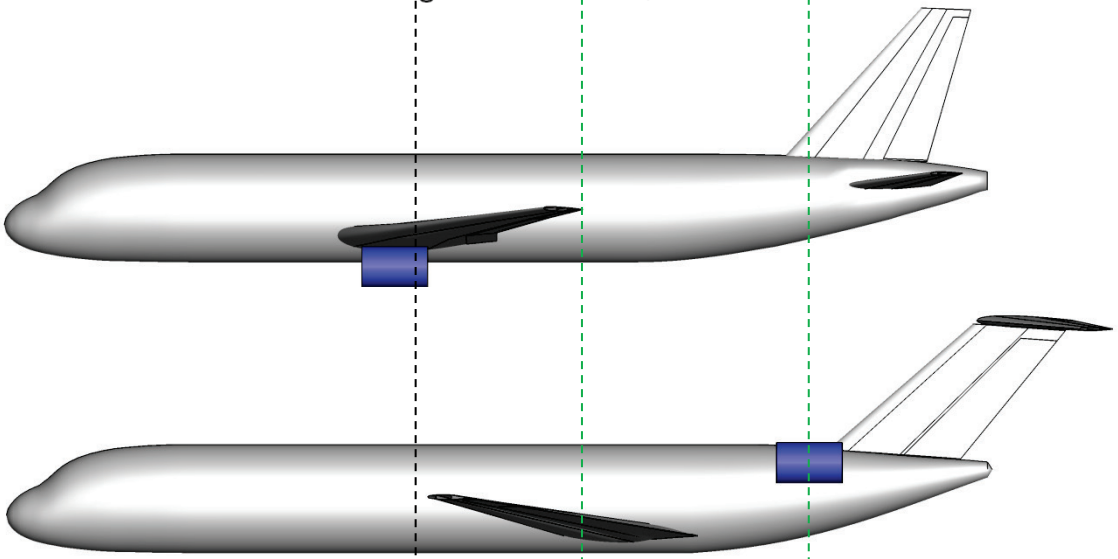
Forward Swept Wing



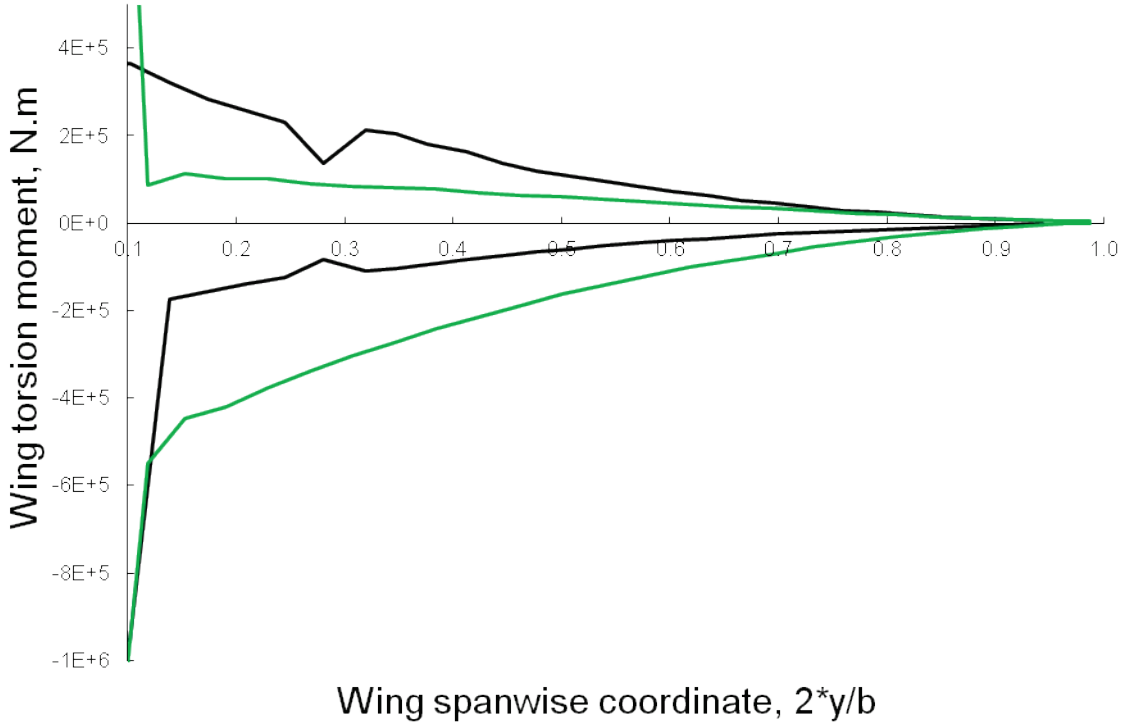

Wing bending moment, N.m
6E+6
4E+6
2E+6
0E+0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Wing spanwise coordinate, 2*y/b

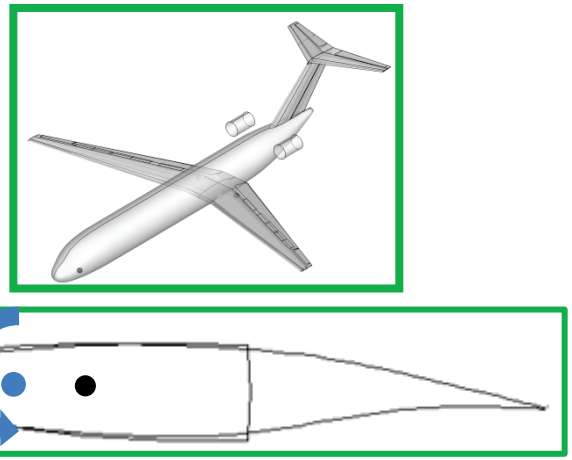

Dashed lines rigid loads
Wing bending moment, N.m
6E+6
4E+6
2E+6
0E+0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Wing spanwise coordinate, 2*y/b

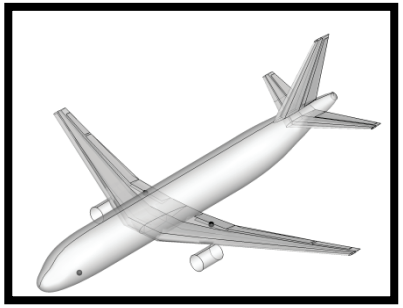

Fuselage bending moment, N.m
9E+6
8E+6
7E+6
6E+6
5E+6
4E+6
3E+6
2E+6
1E+6
0E+0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Fuselage coordinate, x/l

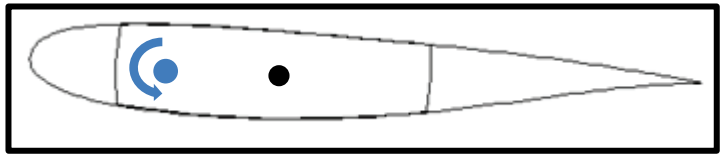


DLR

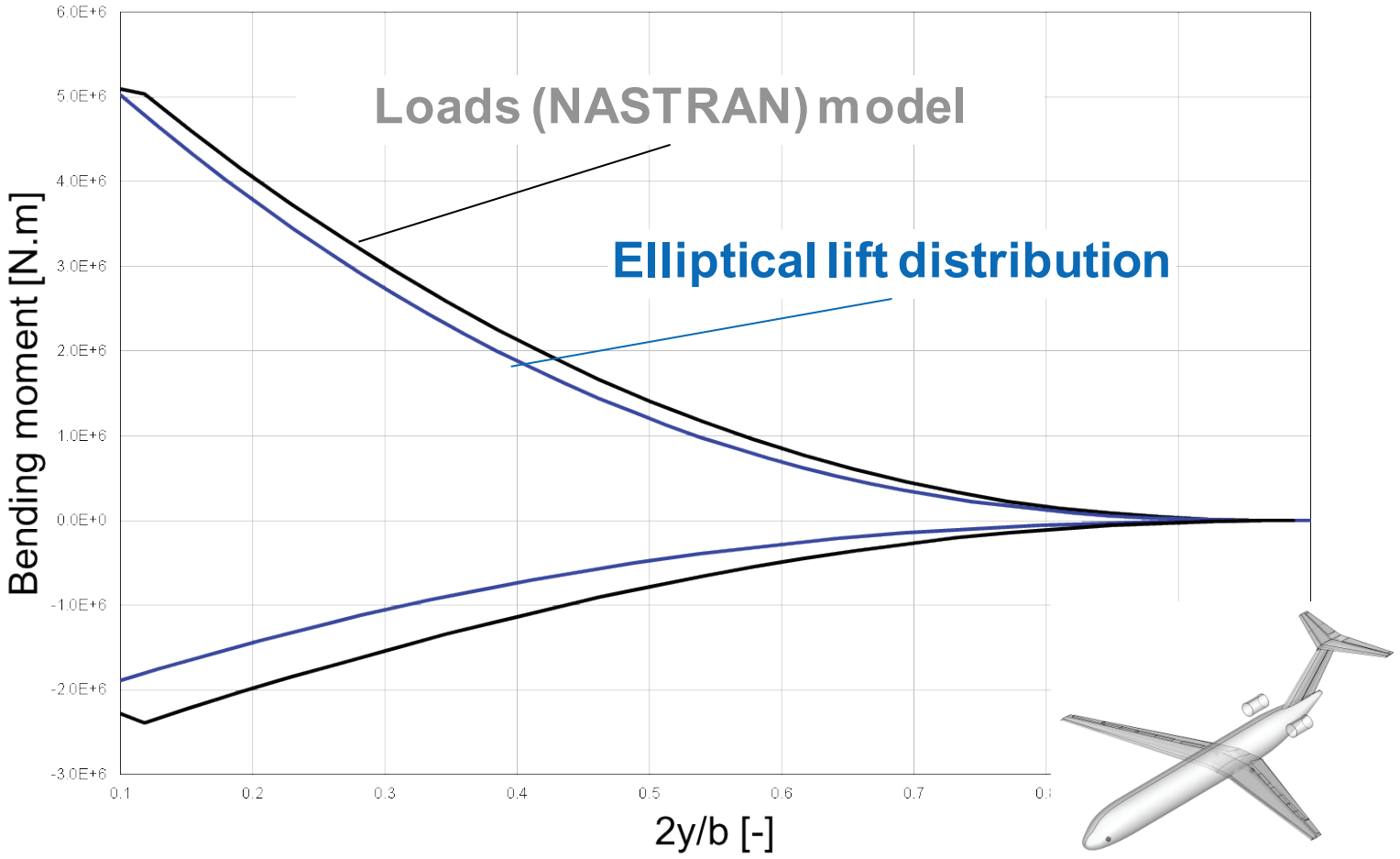

Wing torsion moment, N.m
4E+5
2E+5
0E+0
-2E+5
-4E+5
-6E+5
-8E+5
-1E+6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Wing spanwise coordinate, 2*y/b





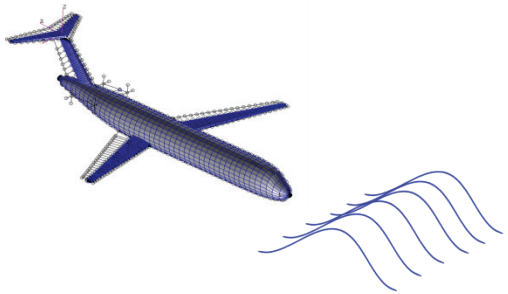


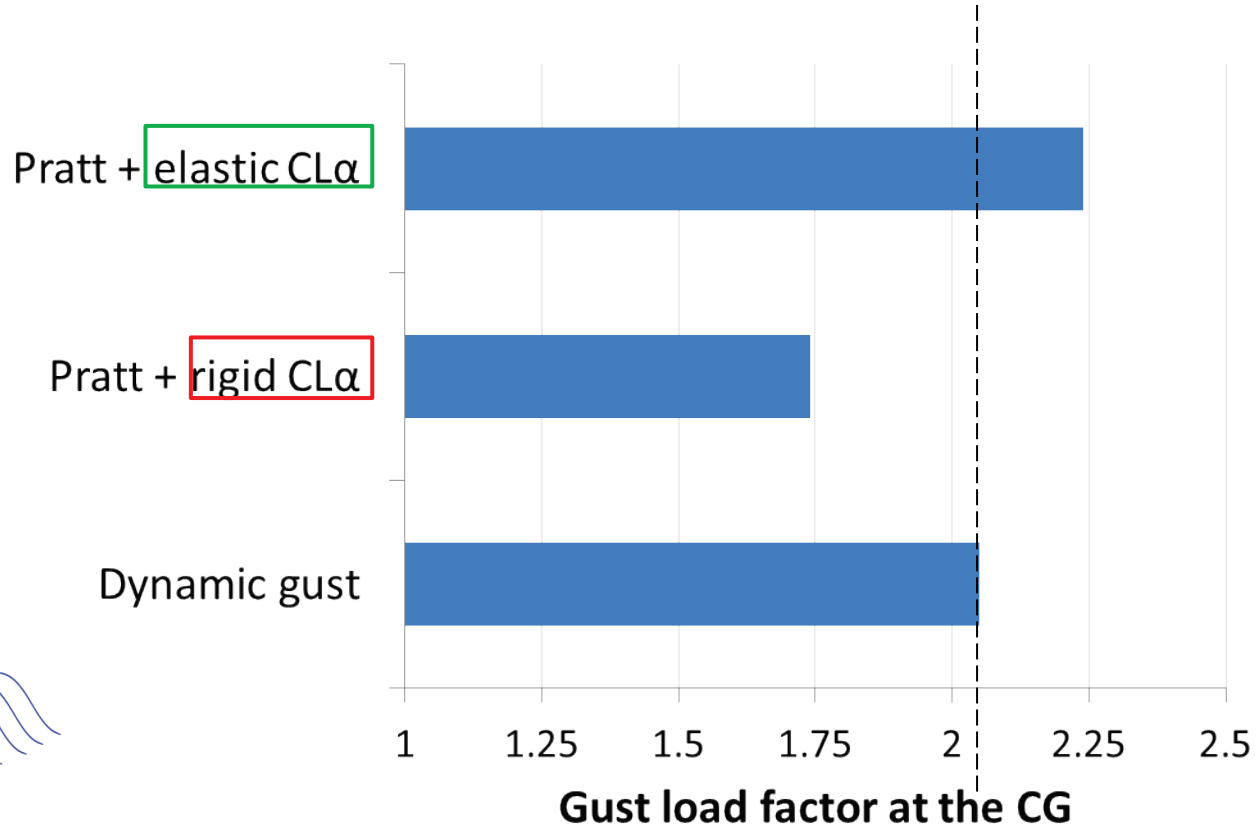
Some remarks about the methods


Loads (NASTRAN) model
Elliptical lift distribution
Bending moment [N.m]
6.0E+6
5.0E+6
4.0E+6
3.0E+6
2.0E+6
1.0E+6
0.0E+0
-1.0E+6
-2.0E+6
-3.0E+6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2y/b [-]

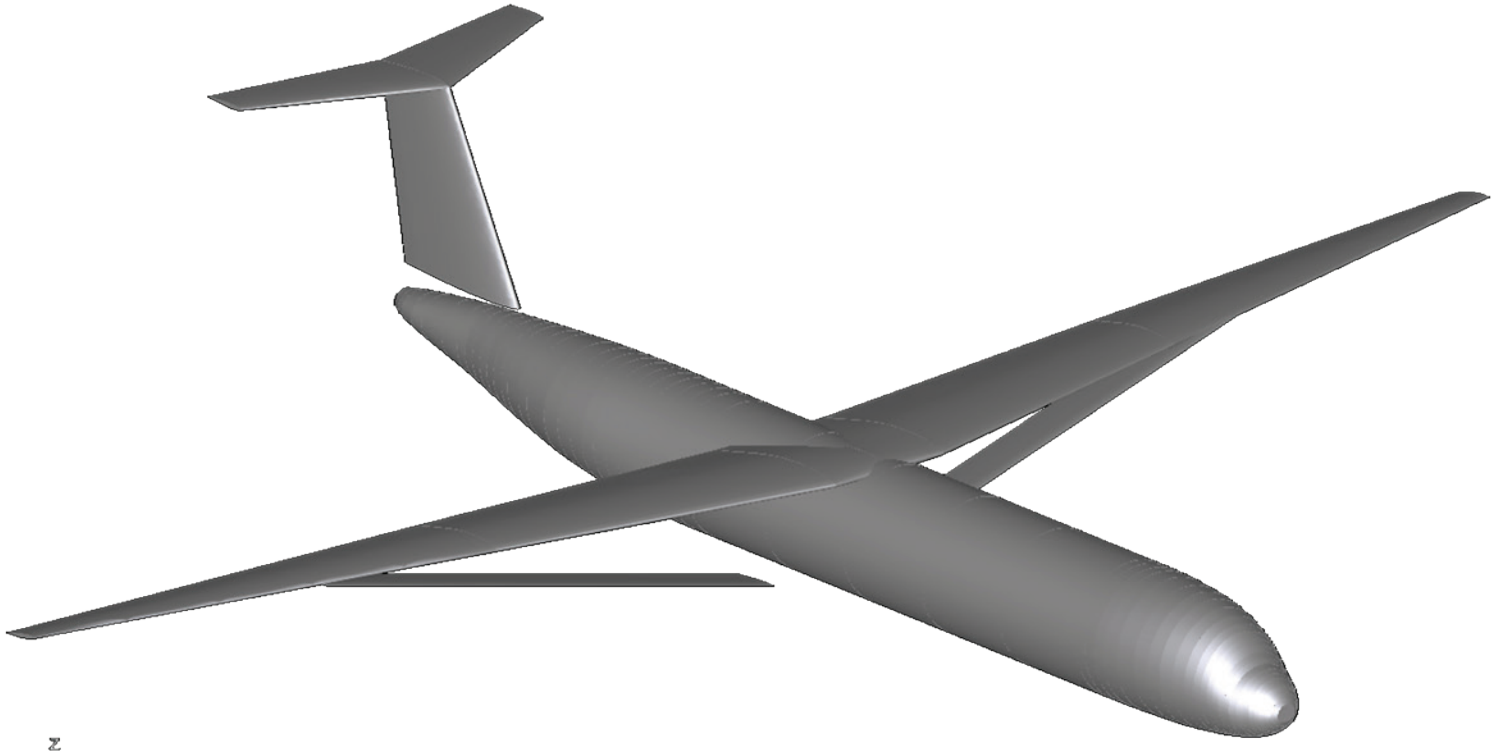
$$\Delta n_z = K_g \frac{\rho\, w_{g0} V C_{L\alpha}}{2\,(W/S)}$$

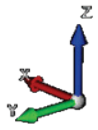
$$\Delta n_z = K_g \frac{\rho\, w_{g0} V C_{L\alpha}}{2\,(W/S)}$$



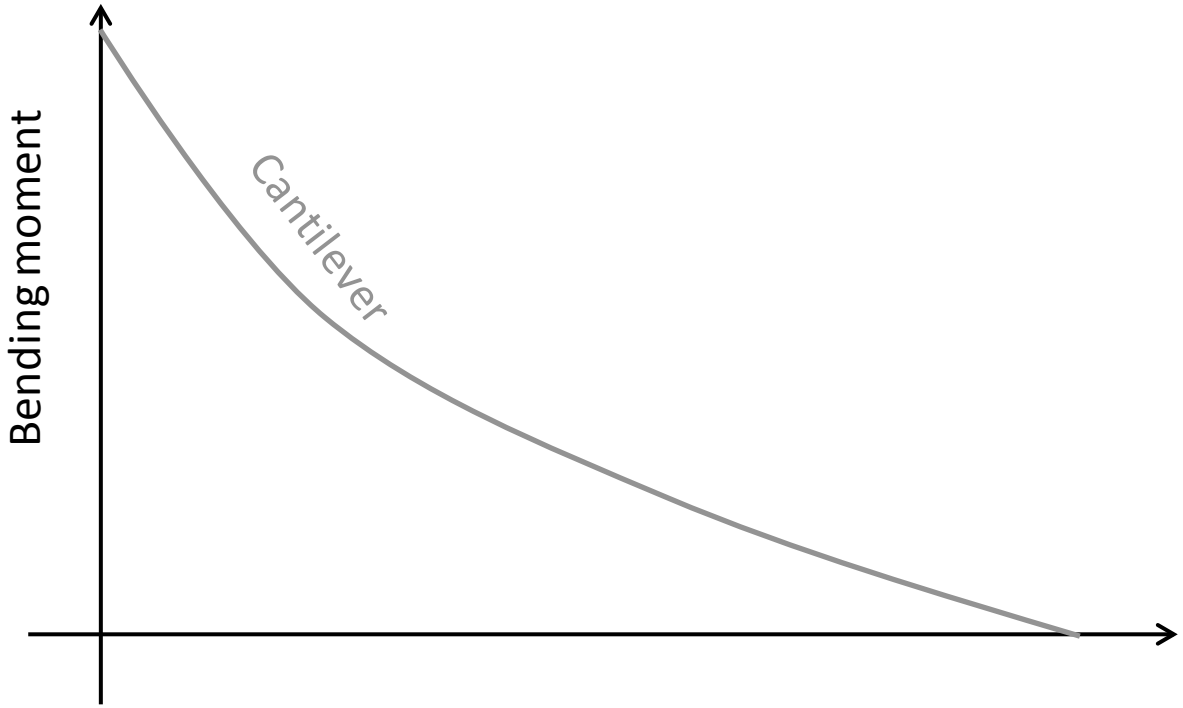


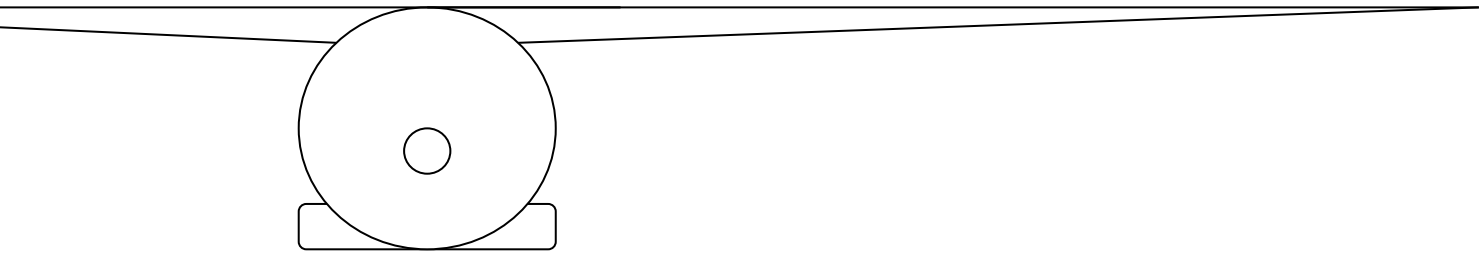
Strut Braced Wing

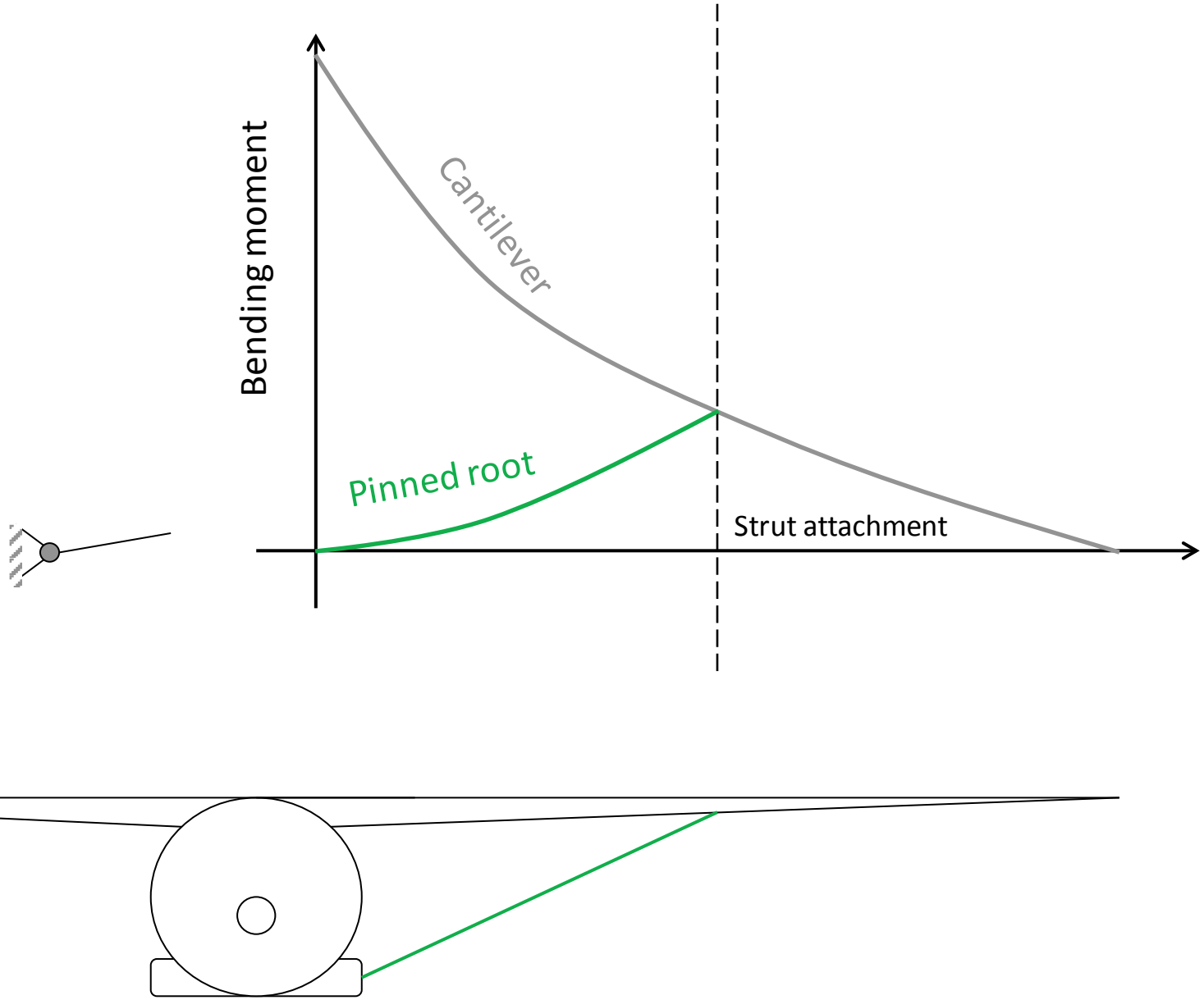


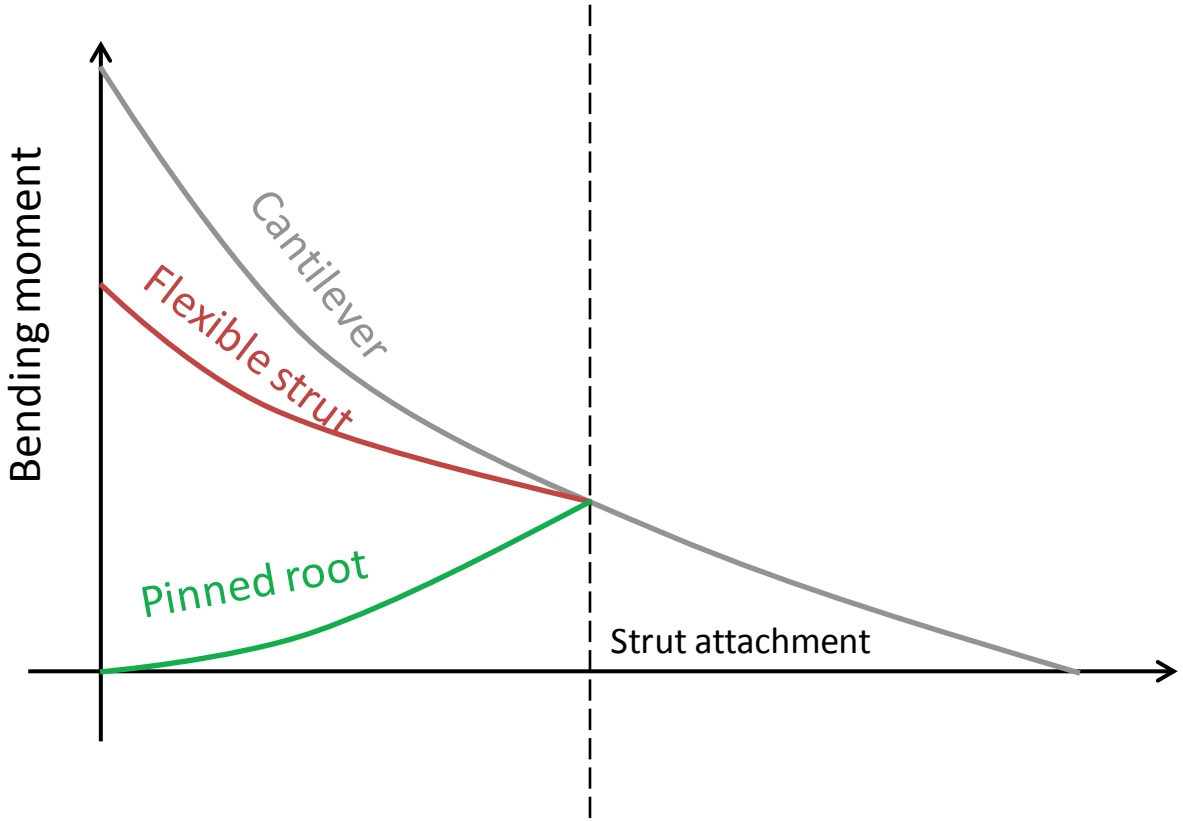


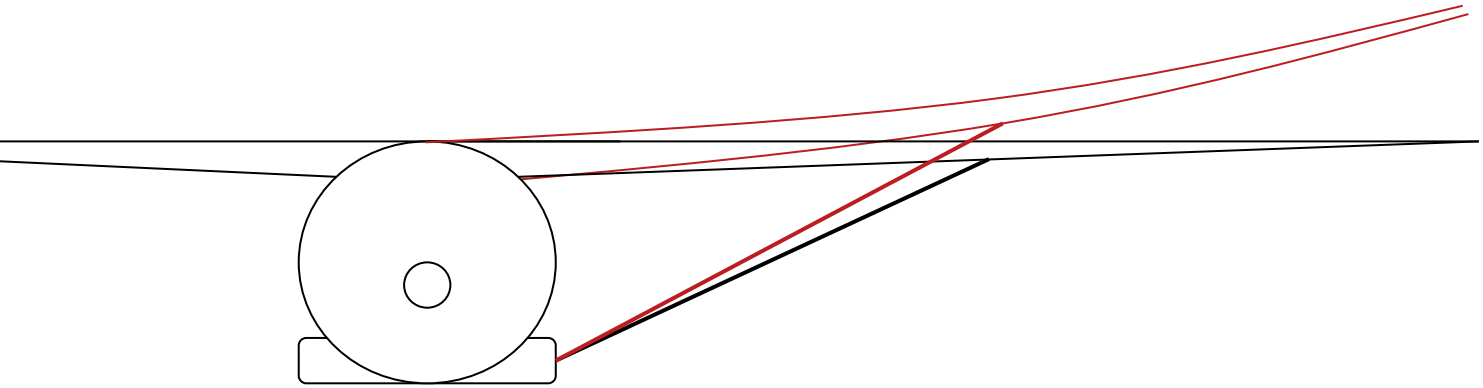
Strut effect on internal loads?

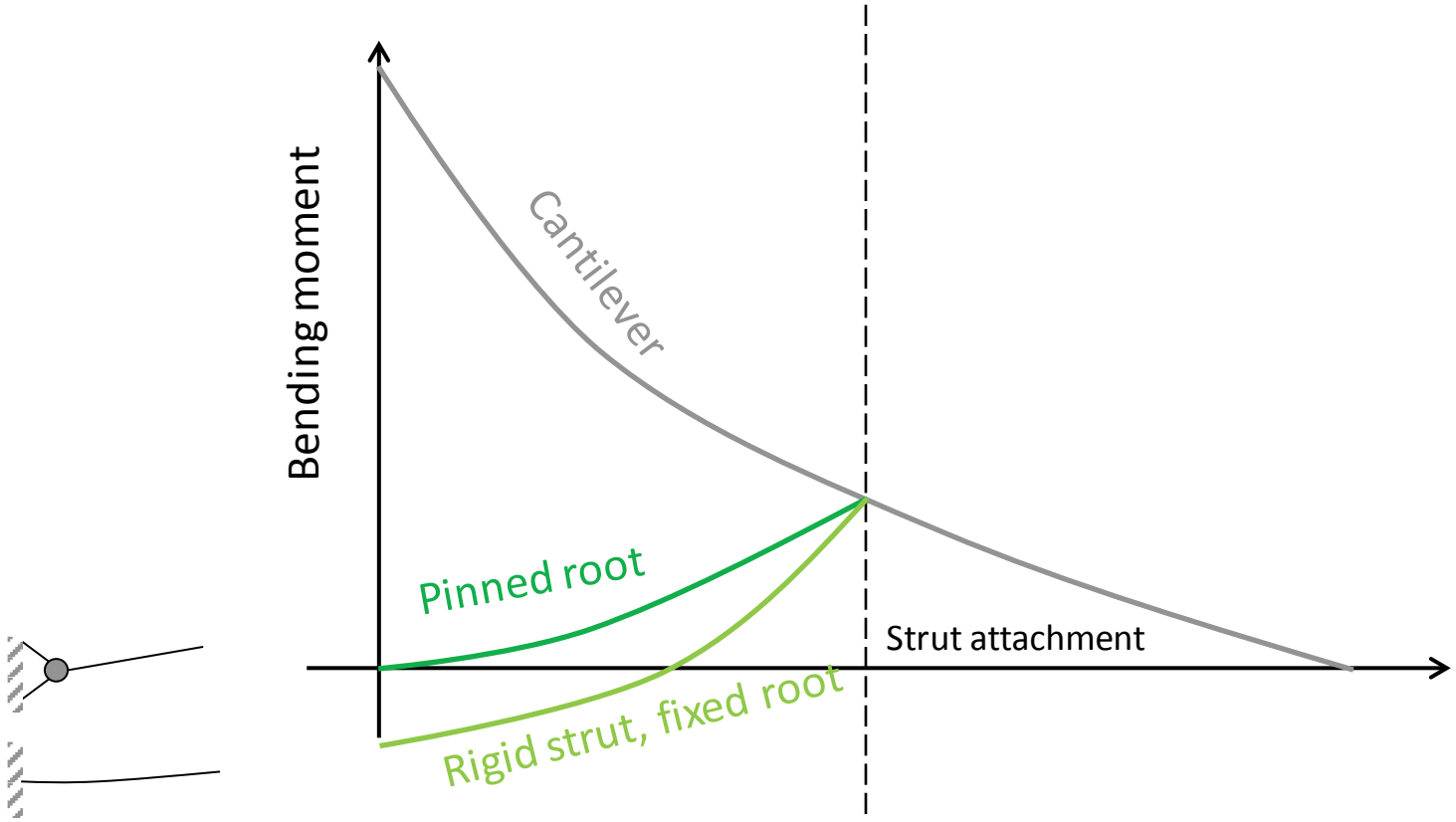

Bending moment
Cantilever

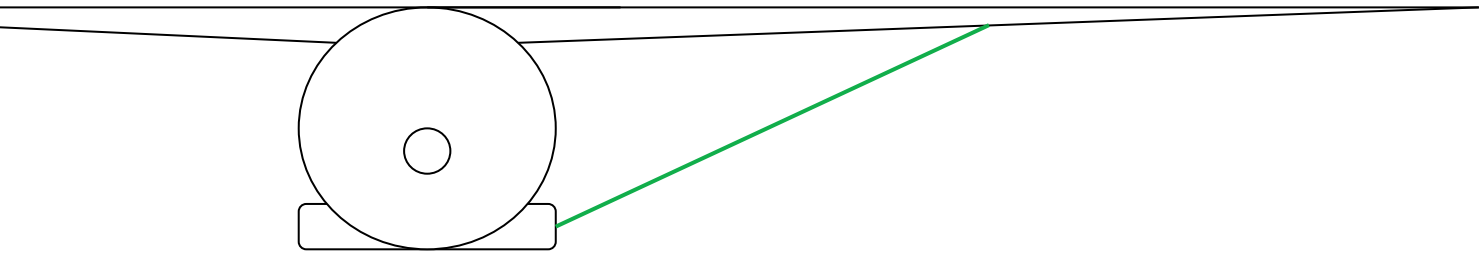


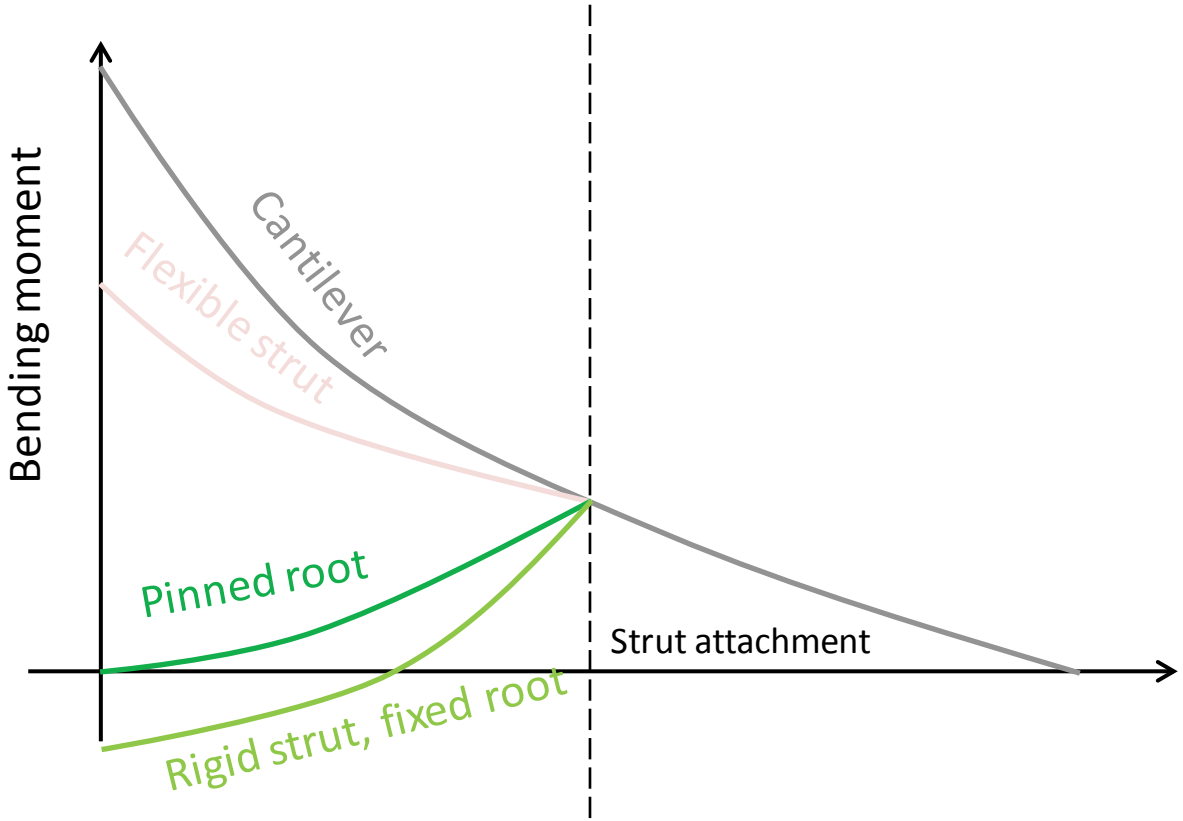

Bending moment
Cantilever
Pinned root
Strut attachment

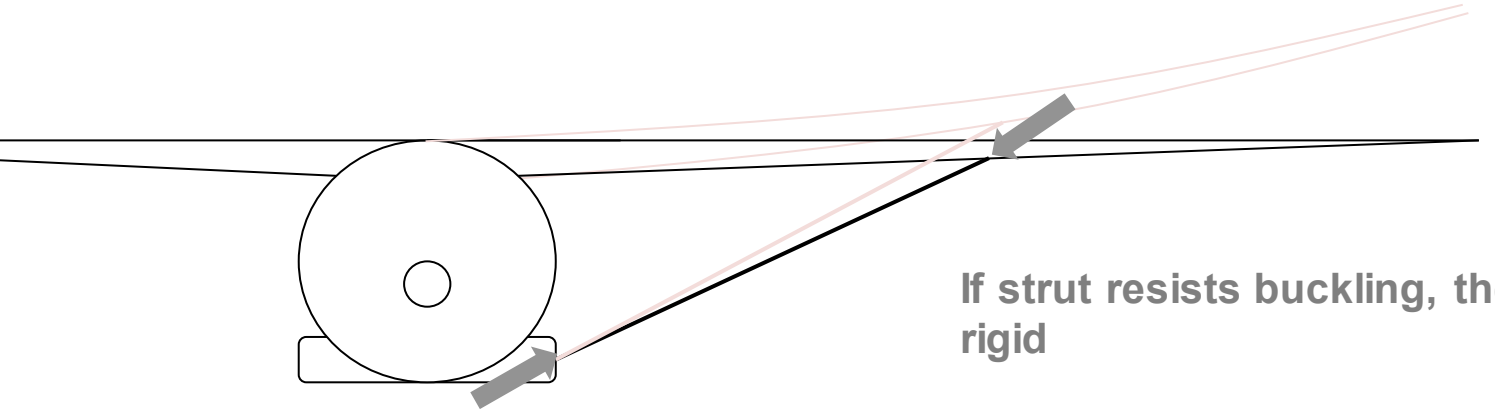

Bending moment
Cantilever
Flexible strut
Pinned root
Strut attachment



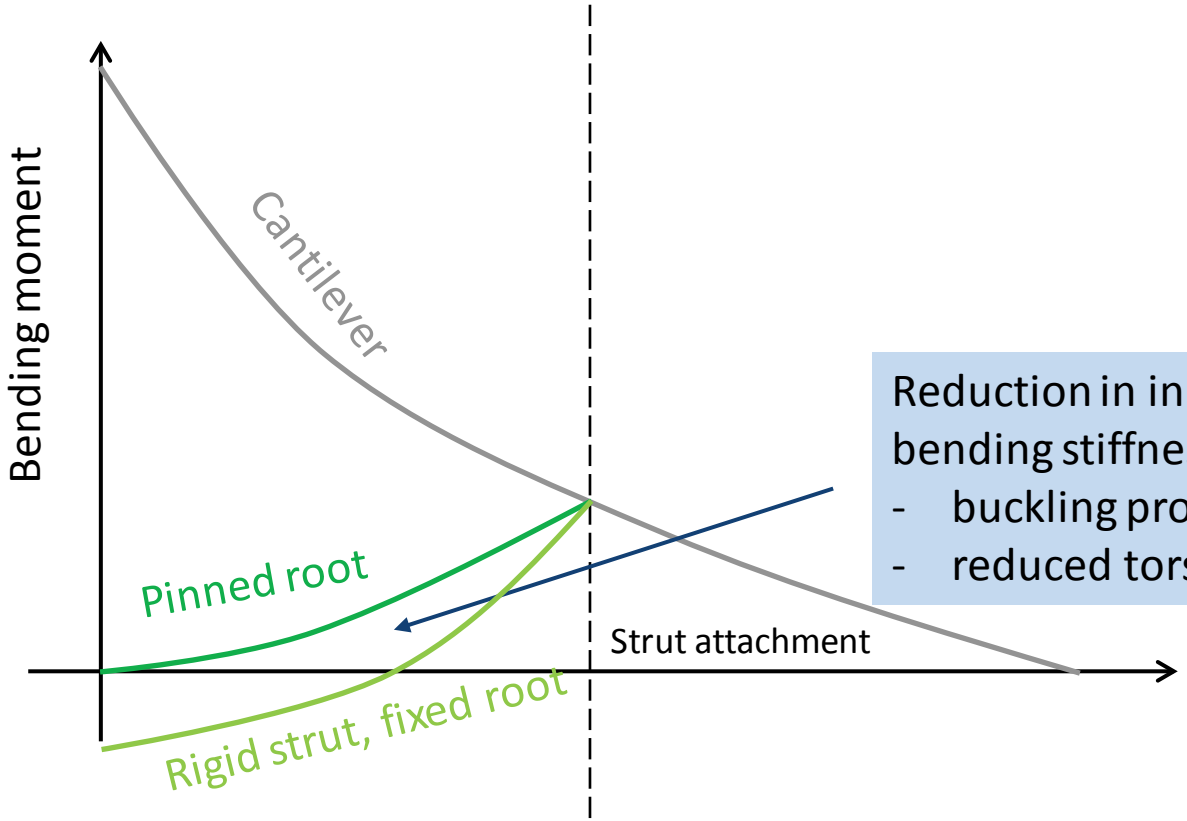

Bending moment
Cantilever
Pinned root
Strut attachment
Rigid strut, fixed root



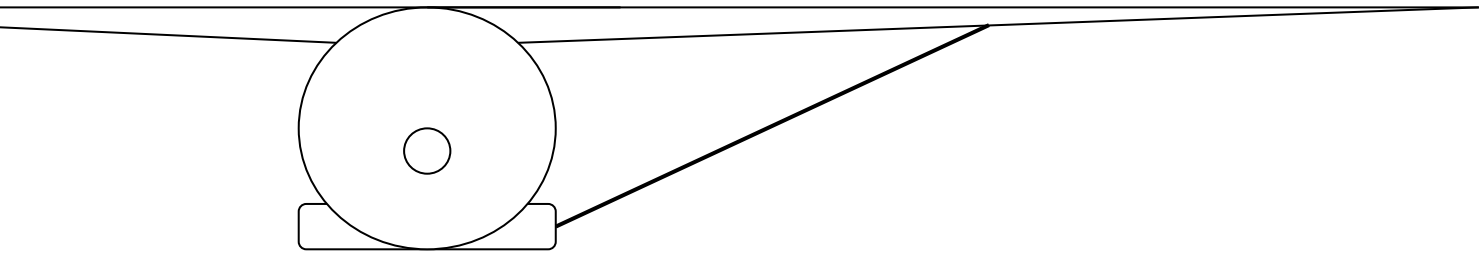


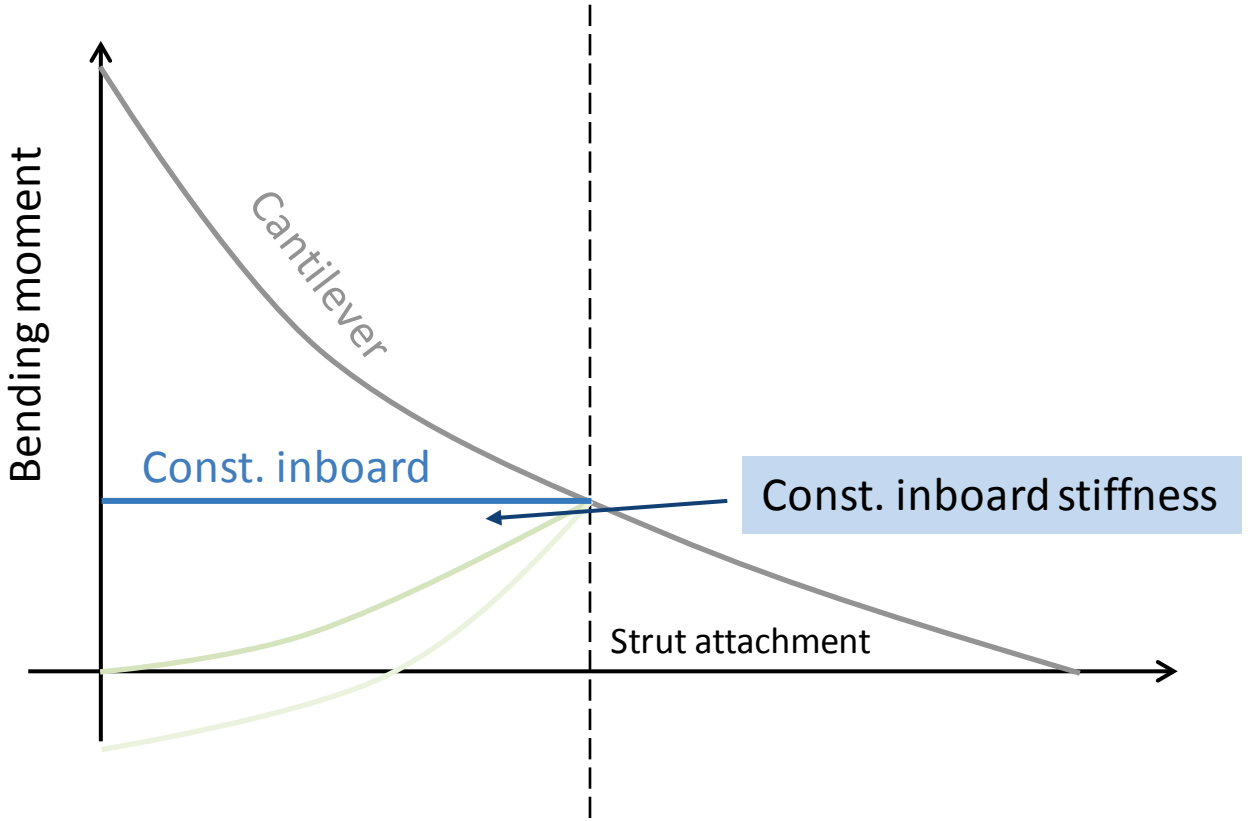


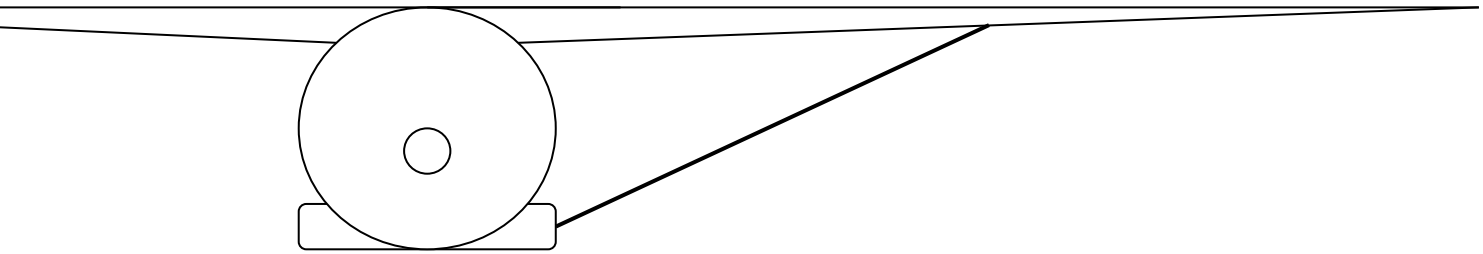
If strut resists buckling, then probably almost rigid

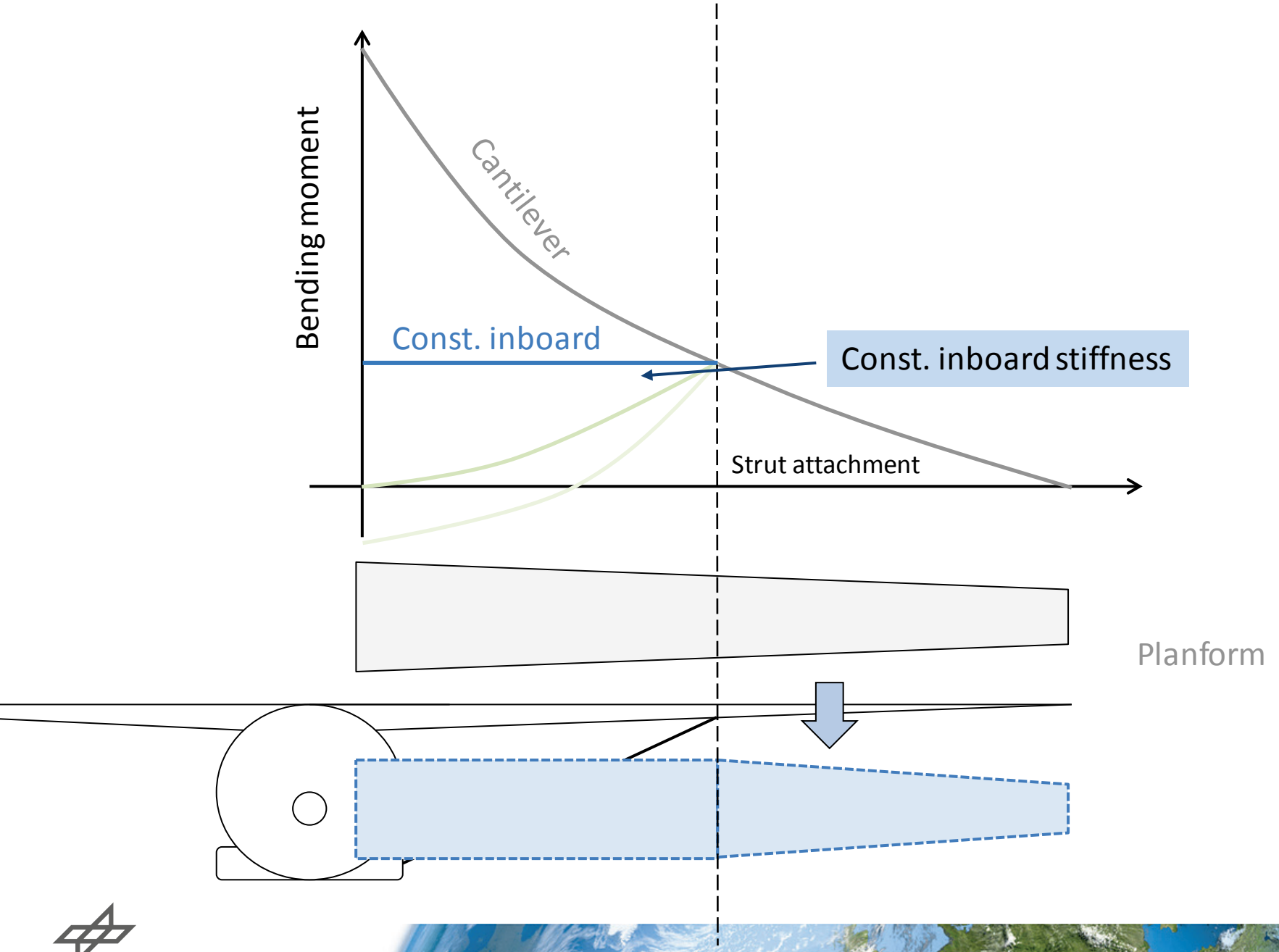


Reduction in inboard bending stiffness undesired
- buckling problems
- reduced torsion stiffness

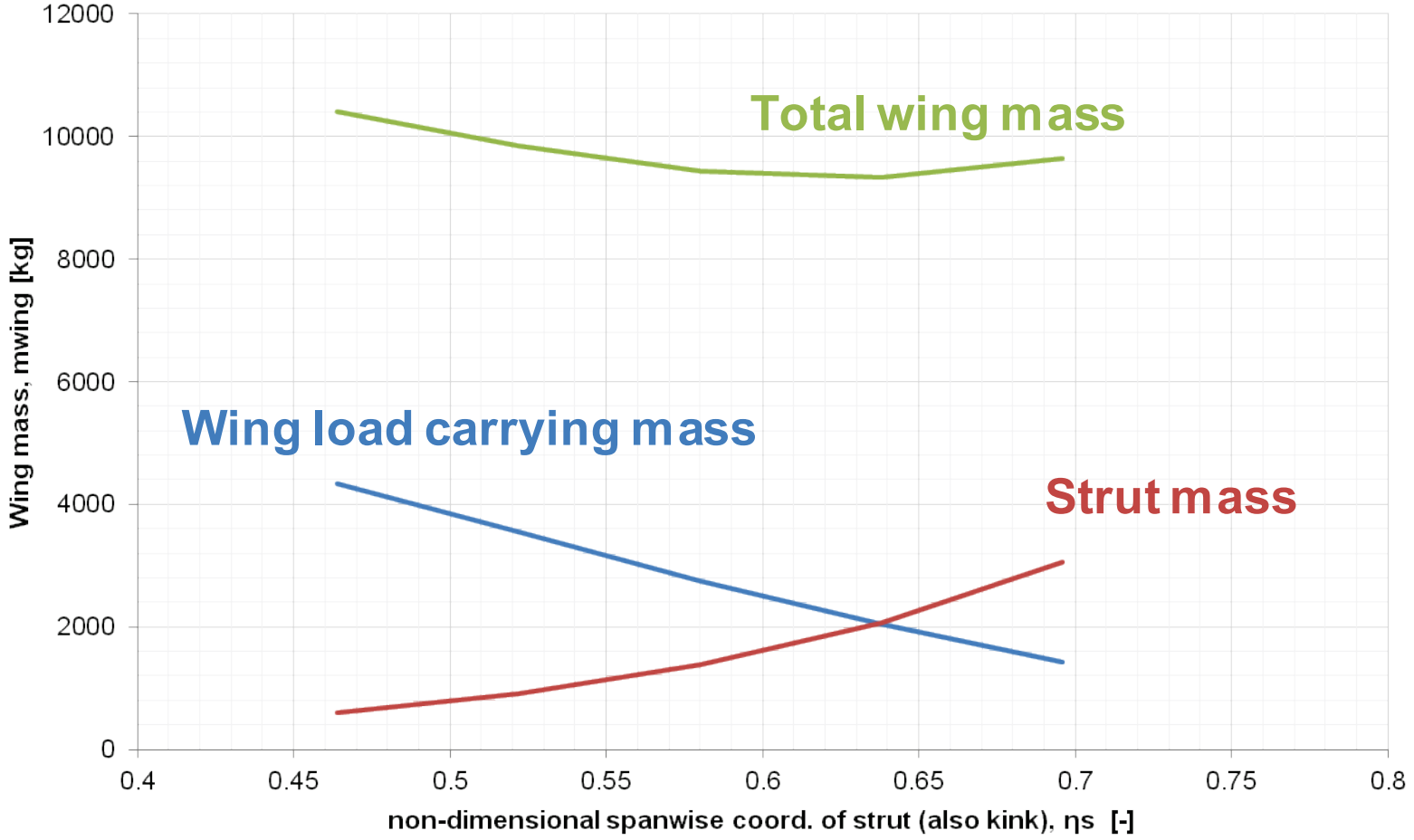


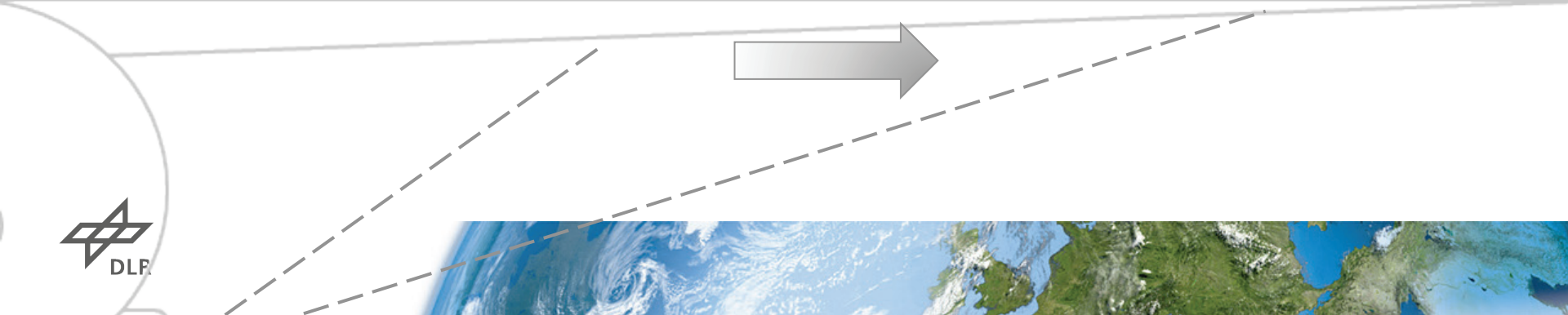

Bending moment
Cantilever
Const. inboard
Const. inboard stiffness
Strut attachment



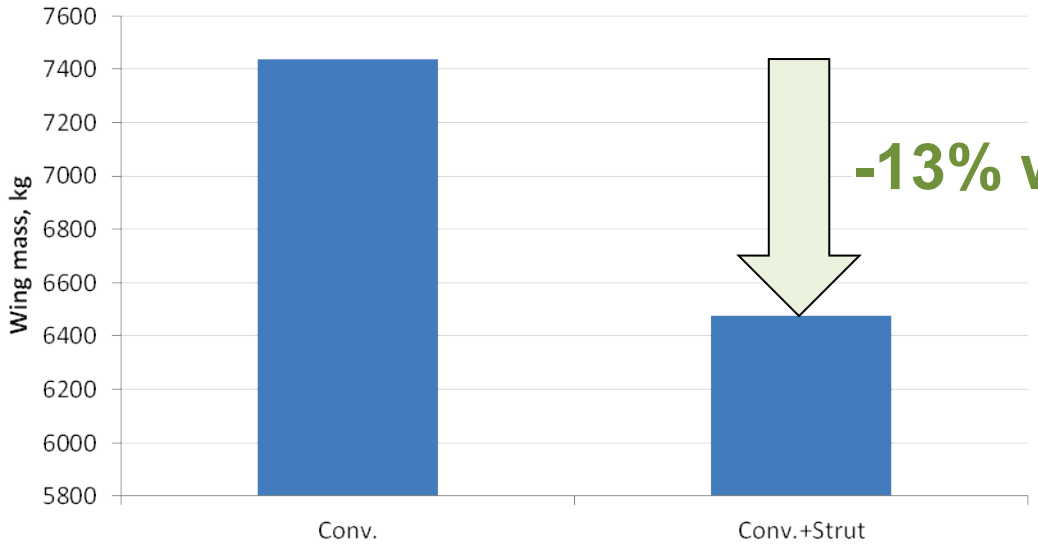

Bending moment
Cantilever
Const. inboard
Const. inboard stiffness
Strut attachment
Planform

Strut position sensitivity?

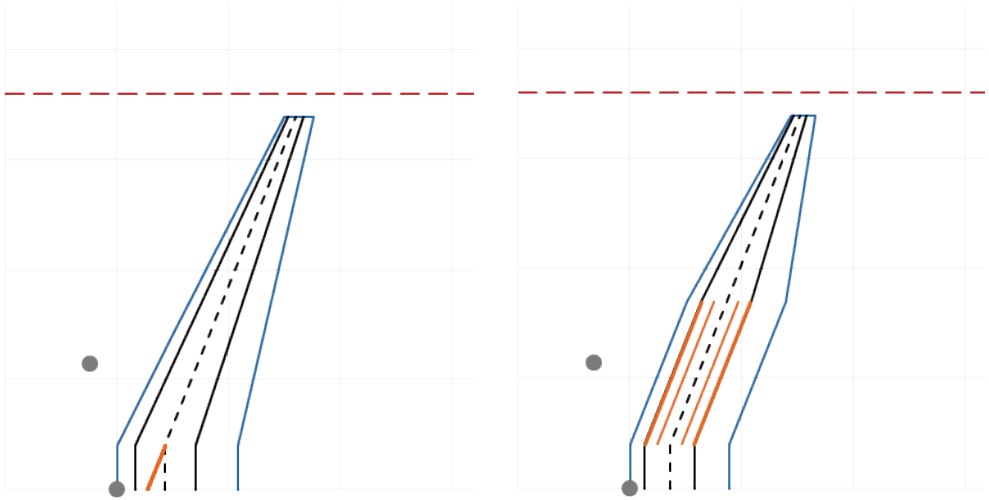

12000
10000
8000
6000
4000
2000
0
Wing mass, mwing [kg]
Total wing mass
Wing load carrying mass
Strut mass
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
non-dimensional spanwise coord. of strut (also kink), ηs [-]



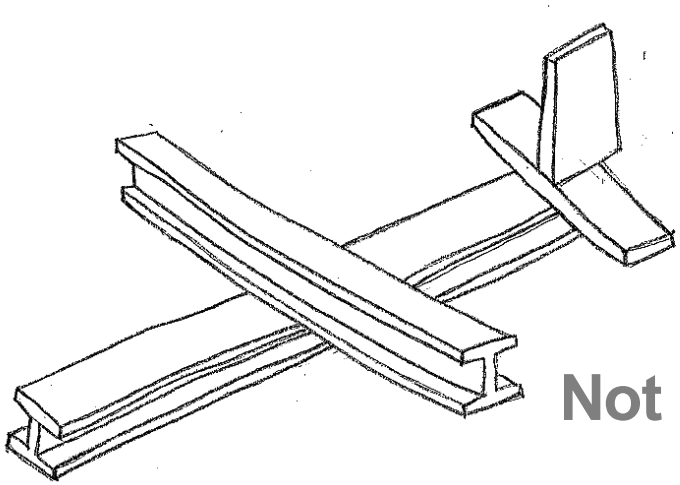
Reduction in wing mass for a conventional planform



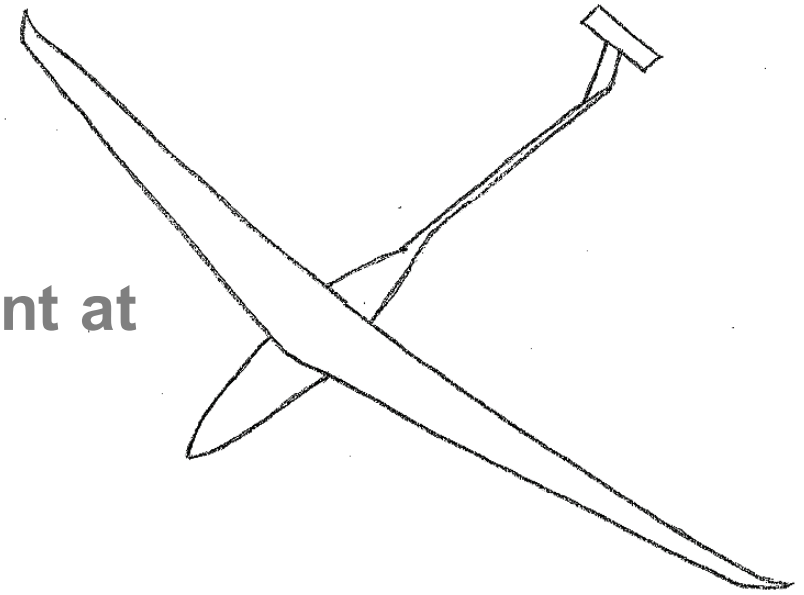
-13% wing mass



DLR

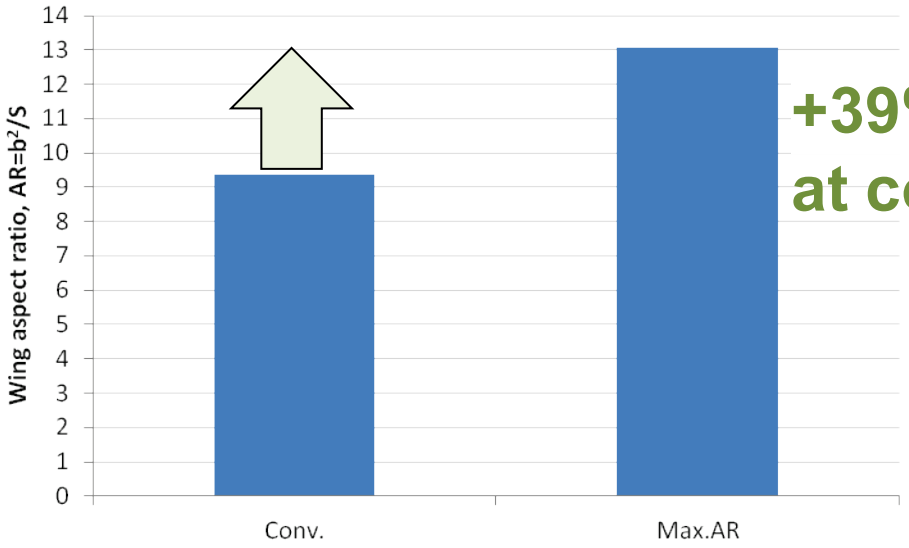


Not only weight reduction is required...

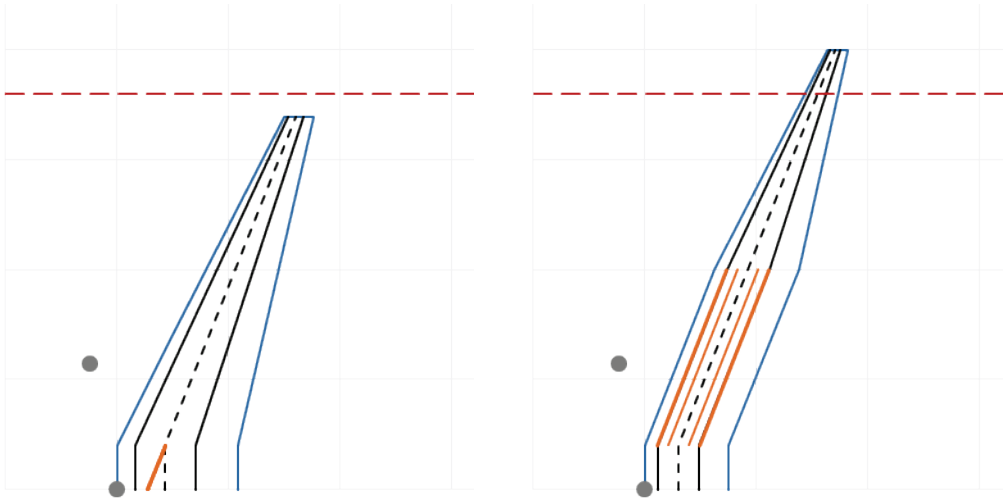


... some aerodynamic improvement at constant mass...

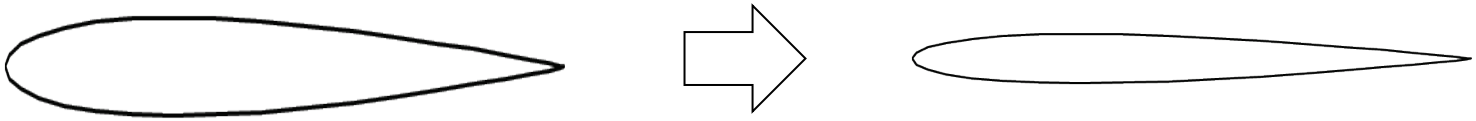
Maximum AR at constant wing mass?

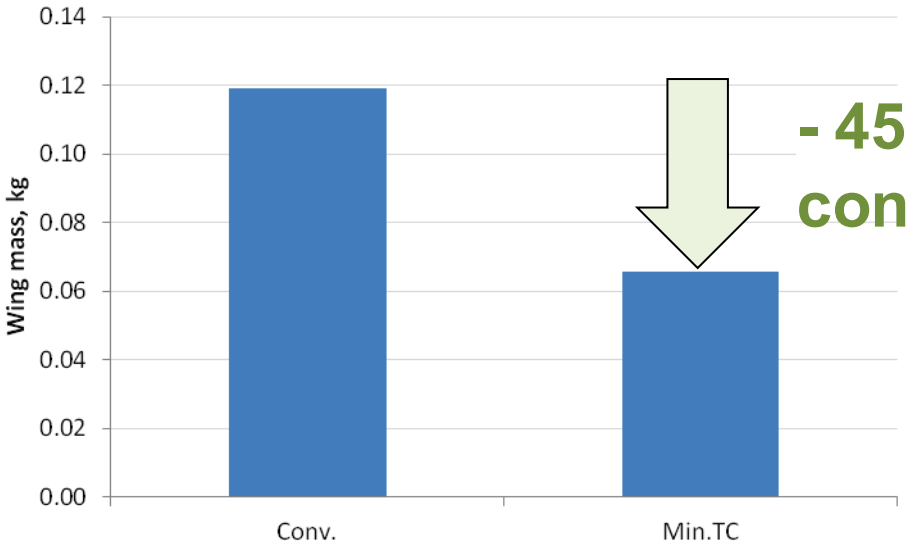


+39% higher AR at const. mass

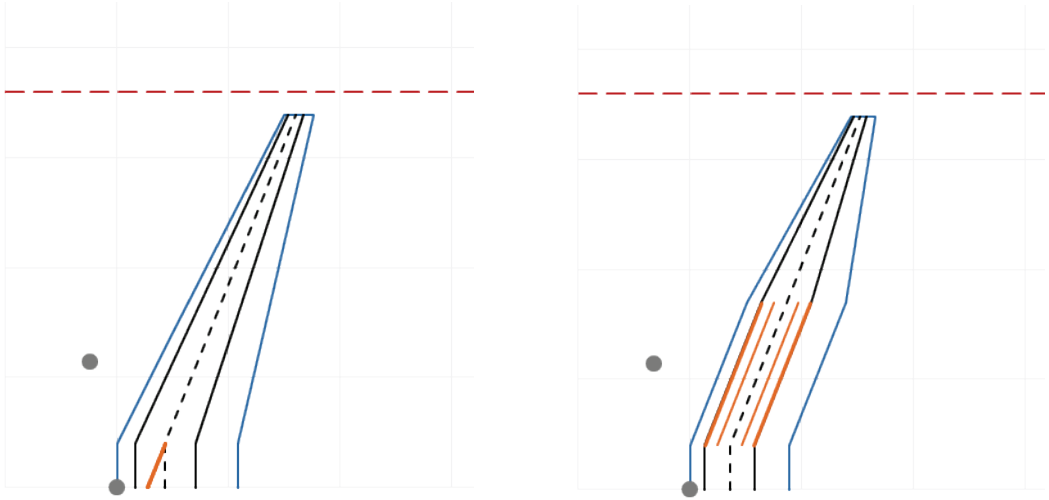


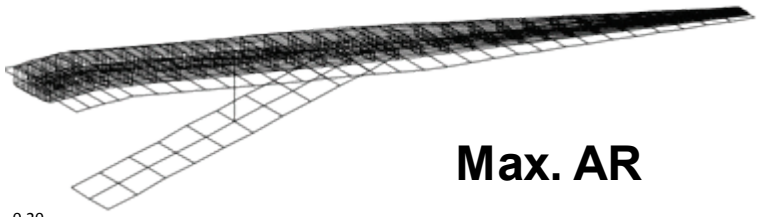
Minimum t/c at constant wing mass?



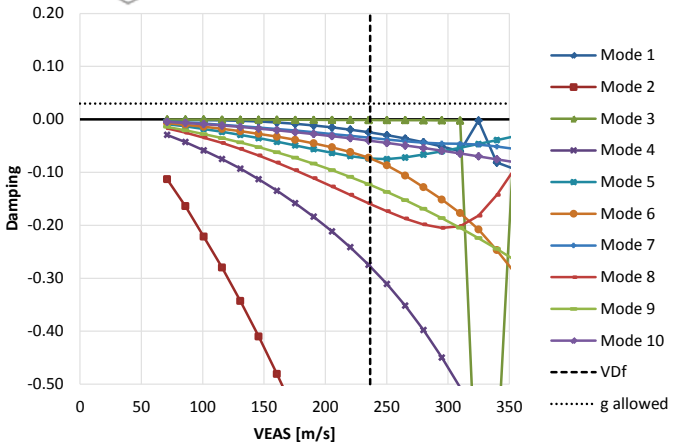


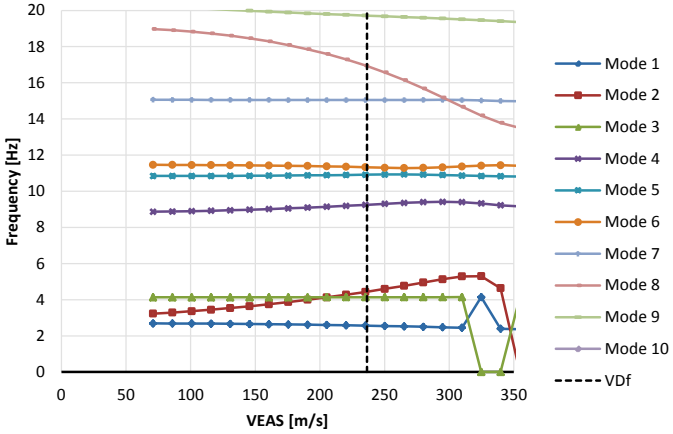
- 45% lower t/c at const. mass

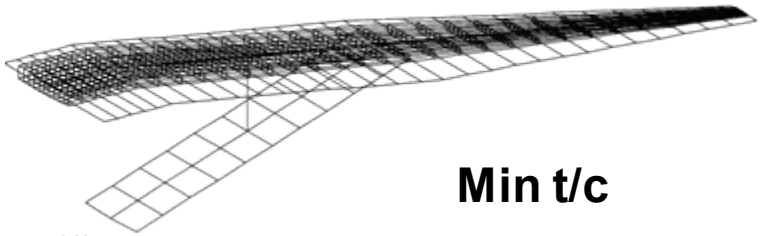




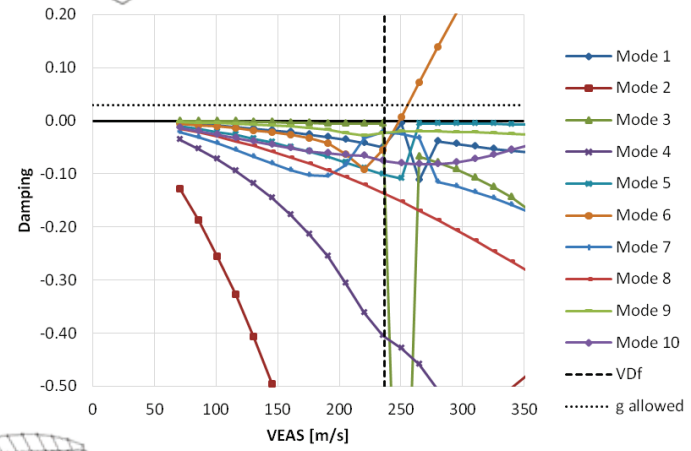
Max. AR

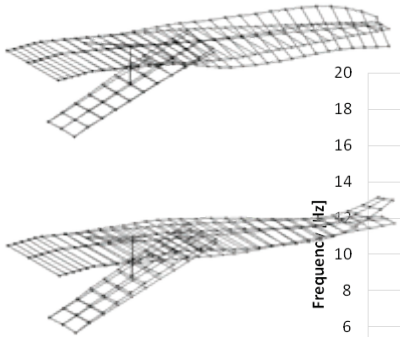

Damping
VEAS [m/s]
Mode 1
Mode 2
Mode 3
Mode 4
Mode 5
Mode 6
Mode 7
Mode 8
Mode 9
Mode 10
VDf
g allowed

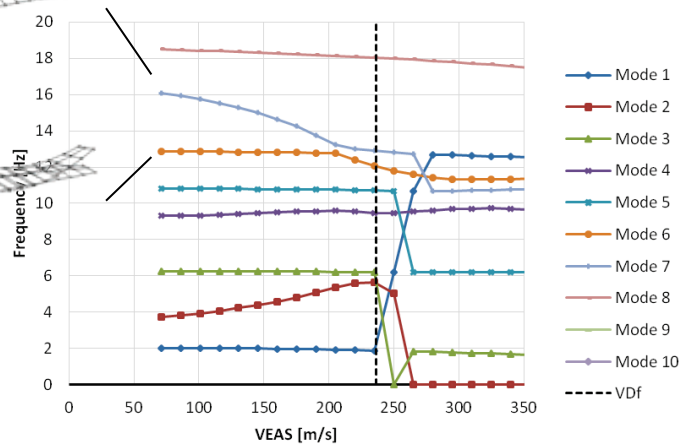

Frequency [Hz]
VEAS [m/s]
Mode 1
Mode 2
Mode 3
Mode 4
Mode 5
Mode 6
Mode 7
Mode 8
Mode 9
Mode 10
VDf



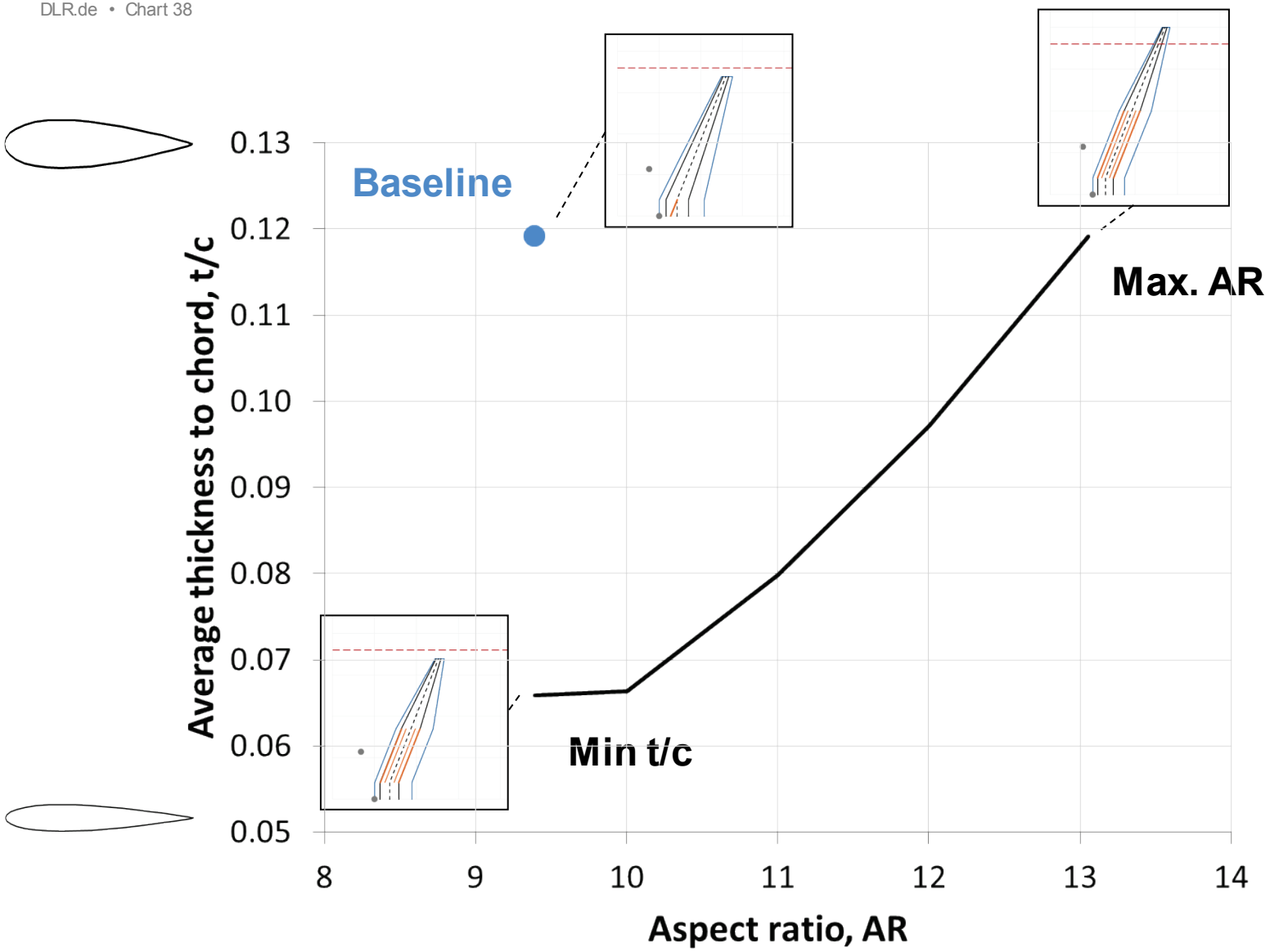
Min t/c

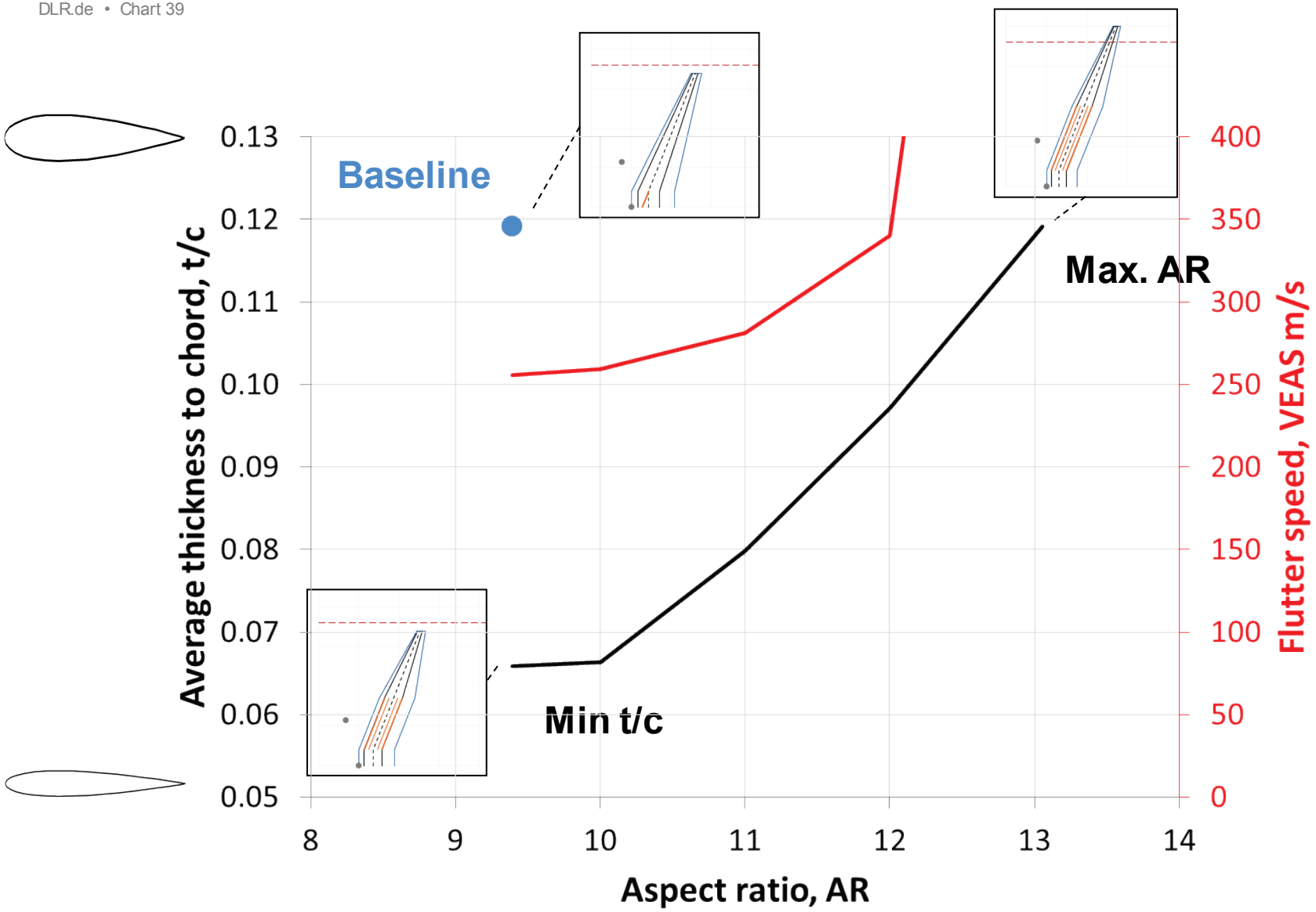

Damping
VEAS [m/s]
Mode 1
Mode 2
Mode 3
Mode 4
Mode 5
Mode 6
Mode 7
Mode 8
Mode 9
Mode 10
VDf
g allowed



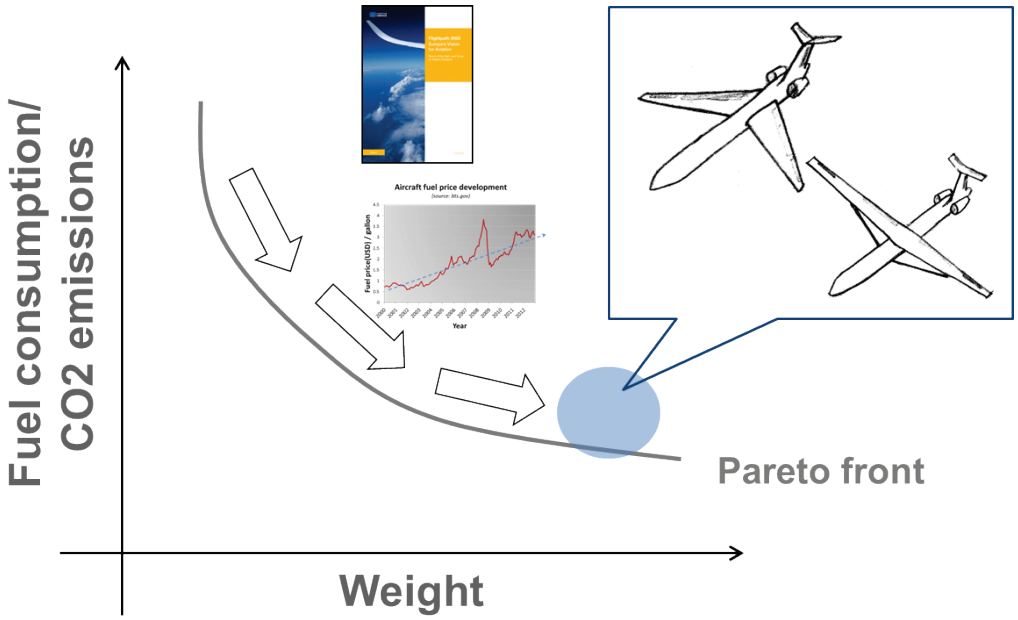

Frequency [Hz]
VEAS [m/s]
Mode 1
Mode 2
Mode 3
Mode 4
Mode 5
Mode 6
Mode 7
Mode 8
Mode 9
Mode 10
VDf

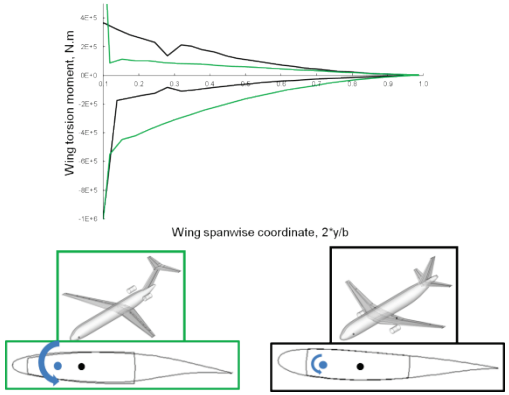
Pareto front:
AR and t/c at constant wing mass

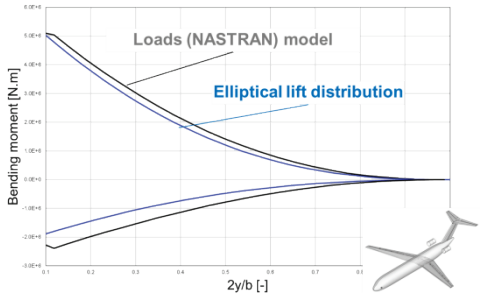

Baseline
Max. AR
Min t/c
Average thickness to chord, t/c
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
8
9
10
11
12
13
14
Aspect ratio, AR

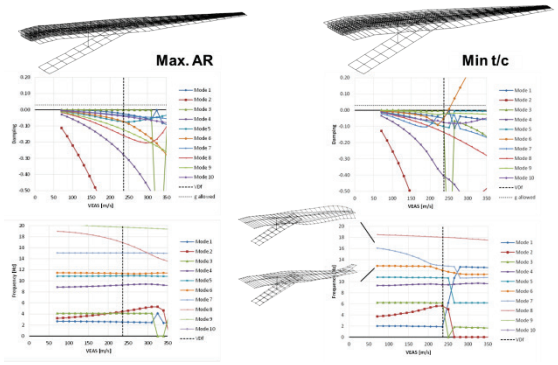

Baseline
Max. AR
Min t/c
Average thickness to chord, t/c
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
Flutter speed, VEAS m/s
400
350
300
250
200
150
100
50
0
8
9
10
11
12
13
14
Aspect ratio, AR

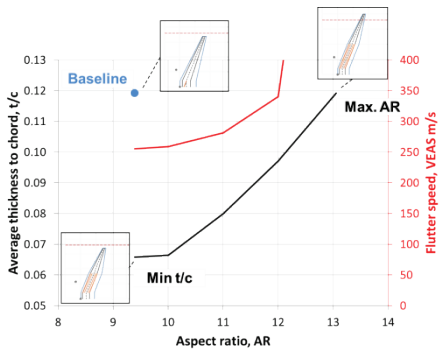
Conclusion











Constant wing mass !

Thank you for your attention!